PUBLISHED MONTHLY

SUBSCRIPTION PRICE $1.75 PER YEAR

No. 149. PRICE 15 CENTS MAR. 1892

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ELECTRICITY

THE SCIENCE OF THE NINETEENTH CENTURY

BY

E. M. CAILLARD

PART II. (ILLUSTRATED)

NEW YORK
HUMBOLDT PUBLISHING COMPANY
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are not exactly the same as those obtained from an electrical machine or a Leyden jar; for beside the spark proper, there is an aureole or glow which surrounds it, and which by the help of a suitable apparatus can be detached from it, thus showing that the two appearances are caused by different discharges. Experiments of various kinds seem to prove that the sharply-defined spark is analogous to that given by a battery on breaking circuit, and that the aureole is caused by the quiet combination of the opposite kinds of electricity in the same manner as in a galvanic current.[1] The sparks from induction coils are specially suitable for passing through Geissler's tubes, and are very often used for this purpose in preference to those from an electrical machine. Very beautiful luminous effects are then obtained, especially if the tubes are made of uranium glass, or contain a solution of quinine or other "fluorescent" liquid. By fluorescence is meant the property possessed by some substances of changing the color of rays of light through altering their arrangibility; phosphorescence is the power of becoming self-luminous, a property which can be conferred by the passage of an electric discharge on that part of a very highly rarefied gaseous medium near the negative pole. The phenomena of fluoresence and phosphorescence, though somewhat complicated, present points of the highest interest and importance, and a hope seems even to be entertained by some of our leading scientists, that in the course of time discoveries will be made enabling us to produce for ordinary purposes artificial light of this description, which is unaccompanied by heat. In fact, experiments in this direction were made by Professors Ayrton and Perry so far back as 1879.

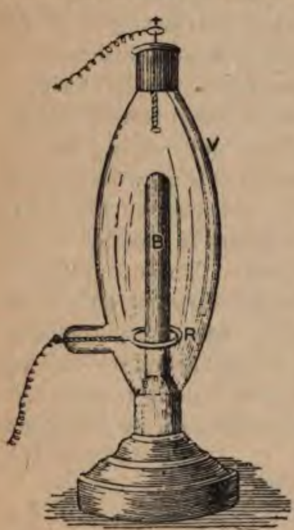

FIG. 26.

An exceedingly interesting and instructive experiment can be made with a magnet on the luminous discharge in a Geissler's tube, such a discharge possessing the properties of an electric current so that it deflects the magnetic needle, and is itself capable of being acted on by a magnet. Fig. 26. will enable this experiment to be understood. A soft iron bar (B) is enclosed in an exhausted glass vessel (V), and is surrounded at the lower end by a metallic ring (R), and carefully insulated. The terminals of a battery are then connected, one with the upper end of the apparatus and the other with the metal ring, and immediately a sheaf of luminous rays descends

[1] "Electricity in the Service of Man," p. 199.

toward the ring, surrounding the soft iron bar. If while the luminous discharge is thus passing, one pole of a magnet be held under the vessel, the iron bar becomes magnetized, and the rays of light begin to revolve round it, thus giving a striking proof both of the rotary tendency of the magnetic forces and of their effect on an electric discharge.

It must not be supposed that induction currents show themselves only in wires. Solid bars or masses of metal of any shape are susceptible of them, and a magnet moved in the neighborhood of a lump or plate of metal, or the starting or stopping of an electric current near it, induces in it currents which, owing to the resistance they encounter, very rapidly transform their energy into that of heat, and while they last tend to stop the motion of the magnet which gave rise to them. This they do in accordance with a law, known as *Lenz's law*, from the name of its formulator, by which all induced currents flow in such a direction that their reaction tends to stop the motion producing them. They thus, in fact, offer a mechanical resistance, which is experienced by any conductor constrained to move across the lines of force in a magnetic field. A curious and striking instance can be given of this by suspending a metal disc by a twisted thread, between the poles of two powerful electro-magnets. While the magnets are inactive the disc revolves rapidly through the untwisting of the thread, but directly the current passes through the coils the disc stops dead, and if forcibly compelled to rotate, grows rapidly hot, showing how powerful is the resistance encountered.

It has been discovered not only that primary currents give rise to secondary currents, but also that the latter are themselves able to induce currents in closed circuits near them, and not in any way connected with the primary. Thus, suppose that near the secondary coil a third coil is placed, and near this a fourth. When a current commences in the secondary coil an inverse current is induced in the third coil, and a direct current on its cessation. These currents in the third coil give rise in like manner to momentary currents in the fourth coil, and the process may be almost indefinitely repeated. Currents thus induced by the action of that in the secondary coil, are called *currents of the higher order*, and are said to belong to the third, fourth, or fifth order, etc., according to the remoteness of their generation from the secondary.

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we shall get a weak current, just as we should get a feeble outflow of water at the tap in spite of the former being at high pressure, if it had to flow through a partially choked pipe. In fact, strength of current means the quantity of electricity flowing past a given point in a given time, and therefore it is necessary to be able to measure, and to have a unit of measurement for

Quantity of electricity. Electro-motive force is indeed independent of it, but since strength of current is actually the quantity of electricity flowing per second past a given point in a conductor, this strength can be augmented in two ways, either by increasing the electro-motive, *i.e.*, the driving, force, or by making the current larger. The pressure of falling water in a pipe is not increased by increasing the size of the pipe, but by increasing the difference of level; yet, other things being equal, the strongest stream of water will issue from the largest pipe simply because it is the largest and holds the most water. In the same way electro-motive force is not increased by doubling or trebling the quantity of electricity conveyed by a given conductor, but by doubling or trebling the difference of potential between the two ends of that conductor; yet the electro-motive force being the same, a stronger current will flow through a thick than through a thin wire, merely because its thickness allows of the passage of a greater quantity of electricity through the same distance in the same time.

Having thus described what there is to measure in an electric current, the list of units can now be given.

The volt (derived from Volta) is the unit of electro-motive force.[1] It is defined as the difference of potential that must be maintained at the ends of a wire of one ohm resistance, so that a current of one ampère may pass through it.

The ohm is the unit of resistance, and is equivalent to the resistance of a column of mercury one millimetre square and 106 centimetres in length, at a temperature of 0° Centigrade. One mile of ordinary iron telegraph wire has a resistance of from 10 to 20 ohms.

The ampère is the unit of strength of current, and may be defined as a current strong enough to deposit 0.000329 (329 millionths) of a gramme of copper per second on one of the plates of a copper voltameter.

The coulomb is the unit of quantity, and means that quantity flowing in one second past the cross-section of a conductor conveying an ampère.

[1] For practical purposes some particular cell (a standard Daniell's, for example), whose electro-motive force is as nearly as possible one volt, and whose constancy can be depended on, is often used as a standard of electro-motive force; but this does not form the scientific standard of the volt, which is not dependent on the electro-motive force of any cell or chemical combination.

Since quantities almost indefinitely greater and smaller than those signified by the above units have to be measured by electricians, prefixes are often used expressing one thousand or one million times more, or one-thousandth or one-millionth part, so as to avoid the inconvenience of writing and reading such enormous numbers as would otherwise be necessary. For instance, the currents in ordinary telegraphy are not measured by ampères, but by milli-ampères (or thousandths of an ampère), and the resistance in a good telegraph insulator not by ohms, but by megohms (millions of ohms). The electro-motive force of a lightning flash would be measured, if it could be measured, by mega-volts (millions of volts), and the strength of telephone currents by micro- (millionth) ampères.

It will be understood that though these practical units have been mentioned only with reference to current measurement, they can also be used for electro-static purposes. The electro-motive force of a Leyden jar (*i. e.*, of the difference of potential between its two coatings), or of any condenser, would be measured in volts, just as would be the electro-motive force of a galvanic battery; and the resistance of any conductor would be expressed in ohms.

It is clear that the electro-static capacity of a conductor, *i. e.*, the amount of electricity which, owing to its size, shape, and position, with reference to other conductors, it is capable of accumulating, must be of great importance in much practical work, and therefore a unit of capacity needs to be added to those already named. It is called a *farad* (from Faraday); and a condenser, which must naturally be the standard of capacity, has a capacity of one farad, when a potential difference of one volt between its two sets of plates charges each of them with one coulomb. A condenser constructed of tinfoil and paraffined paper, like that described in connection with induction coils, is most frequently used in practical work, but if made on the scale of one farad as a unit, it would be so enormous as to be almost impossible of construction, and quite unmanageable for all ordinary purposes if it were constructed. The practical unit of capacity is therefore in reality the microfarad (one-millionth of a farad), and condensers are made graduated in microfarads. Even then, for some purposes (such as "duplexing" submarine cables), condensers containing many thousand square feet of tinfoil are necessary.

PRACTICAL APPLIANCES OF ELECTRICITY.

PART IV.

CHAPTER I.

MAGNETO-ELECTRIC AND DYNAMO-ELECTRIC MACHINES AND ELECTRO-MOTORS.

Number of practical electrical appliances in modern days—Magneto-electric machines—Pixii's machine—Clarke's machine—Wilde's machine—Siemens' cylindrical armature—Dynamo machines—Their principle—Origin of their name—Now includes magneto-electric machines—Siemens' first self-exciting dynamo—Gramme machine—Principle of Gramme ring—Continuous current machines—Alternate current machines—Various kinds of dynamos—Requisites for a good dynamo—Electro-motors—Their work the converse of that of dynamos—Powerful currents generated by dynamos—Currents of high E. M. F. used for electric lighting—Transformers.

THE practical appliances of electricity in our day are so numerous and so important that it is difficult to know with which to begin. The electric telegraph is the oldest, and has already attained a familiarity which, in this instance, however, certainly does not breed contempt, for no later invention can surpass or perhaps even equal it in the magnitude of its effects on the whole human race. Nevertheless, the more recent adoption of electric lighting and electric transmission of power gives them for the moment a greater prominence in the eyes of the world ; and since it is impossible to gain any notion of their working principles without some knowledge of what is meant by the three classes of machines whose names head this chapter, it will perhaps be as well to commence with them.

Priority of date belongs to the magneto-electric machines, the first of which was constructed in 1833 by Pixii, a scientific instrument maker in Paris. His apparatus consisted of a steel horse-shoe magnet, which was made to revolve rapidly before two wire bobbins, so that its North-seeking and South-seeking poles passed alternately in front of them. Currents were thus induced in the bobbins which changed

direction at every half revolution of the magnet, but which, owing to the way in which the bobbins were wound,[1] would, if the coils were laid end to end, flow through both in the same direction at the same time. Wires connected the apparatus with an outer circuit, through which the currents could be conducted and utilized for any desired object, and in order to obviate the (for many purposes) inconvenient alternations of the currents, a commutator (current reverser) was introduced, by means of which the currents in the outer circuit could be rendered *continuous*, *i. e.*, obliged to flow always in the same direction. Their extremely rapid succession then enabled them for practical purposes to behave as one uninterrupted current. Fig. 27 enables the principle of Pixii's machine to be understood. In its construction, however, the magnet is placed below and not above the coils.

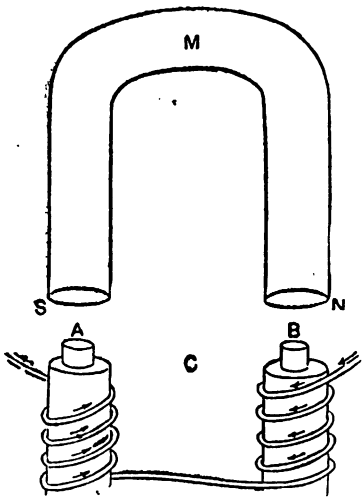

FIG. 27.—To illustrate the principle of Pixii's Machine. M, revolving horse-shoe magnet; A B, soft iron cores surrounded by wire spirals. When S is approaching to and opposite A, and N is approaching to and opposite B, the induced currents flow in the direction indicated by the arrows. When S is approaching to and opposite B, and N is approaching to and opposite A, they flow in the direction opposed to the arrows. In each case there is a momentary cessation of current when one of the magnet poles confronts A and the other B, and a maximum of current when the magnet reaches the position C, so that it is at right angles with the plane of the paper.

The drawback to Pixii's machine lay in the necessity (when a large size was required) of rotating an exceedingly heavy magnet, compelling the expenditure of much mechanical work, for which but a comparatively small return in the shape of electrical energy was made. Clarke and other inventors conceived the idea of making the bobbins revolve before the magnet, instead of the magnet before the bobbins, so that the heaviest part of the apparatus should remain at rest; and much saving of mechanical power was effected in this way. A small portable form of Clarke's machine is still frequently used for medical purposes.

Magneto-electric machines were next improved by constructing them with electro as well as with permanent magnets. In Wilde's machine, one of the best of the earlier kind, the steel horse-shoe magnets are quite small, and used merely to generate currents in a small electro-magnet of cylindrical shape, revolving between their poles, and called an *armature*. The induced currents in this armature are then carried by means of connecting wires through the coils of

[1] See Part III. Chap. iv.

two large fixed electro-magnets, known as the field-magnets, between whose poles another cylindrical armature revolves. The currents thus obtained are exceedingly powerful; but a great drawback to Wilde's machine exists in the large amount of heat it generates, which not only rapidly weakens the current, but makes its constancy a matter of impossibility.

The cylindrical armature used in Wilde's and in many magneto-electric and dynamo machines was invented by Dr. Werner Siemens, one of the four celebrated brothers whose scientific discoveries and appliances are so justly famous. Its utility consists in the fact that, owing to its shape, it is able to revolve in the most powerful part of the magnetic field, *i. e.*, exactly between the poles, thus combining high efficiency with great economy of space. The wire in a Siemens armature is wound lengthwise, like thread in a shuttle, and is enclosed in an iron sheath open at the sides, as represented in Fig. 28. The poles are not situated at the ends of this armature (or electro-magnet), but on the two faces (P P) of the iron sheath which have not been cut away. At every half-revolution of the armature, the polarity is reversed, that which was a North-seeking becoming a South-seeking pole, and *vice versa*.

FIG. 28.—Shuttle-wound Siemens Armature.

The principle of the dynamo machines, shortly stated, consists in utilizing the residual magnetism left in the soft iron core of an electro-magnet as a current generator. Nearly all iron retains a faint remnant of magnetism when once it has been highly magnetized; and therefore an electro-magnet, not externally excited, but rotating as an armature between the poles of two much larger electro-magnets, first induces feeble currents in its own coil, and these being transmitted through the coils of the fixed magnets, render them also active, and consequently able in their turn to exalt the magnetism of the rotating armature by their reaction on it. The armature thus reinforced, itself induces and transmits more powerful currents, to be again strengthened in their passage through the fixed or *field magnets* (thus named because their work is to form a powerful magnetic field for the armature to revolve in), and by this system of continued action and reaction exceedingly strong currents can be obtained in an incredibly short time, and conducted into an outer circuit for use.

The name of dynamos was originally given to machines worked on this principle, because at first sight they appear to owe their electrical energy more directly to the mechanical power expended in rotating the coils than do the magneto-electric machines. Such is not in reality the case, however. Just as both kinds of machines derive

their capability of generating electric currents from electro-magnetic induction, so, also, both kinds must have mechanical energy of some description, be it in the form of hand, horse, steam, or water power, expended on them in order to convert it into electrical energy ; and it has now become common to include them all under the name of dynamos, distinguishing the two classes as magneto and self-exciting dynamos.

The principle of the self-exciting dynamo was simultaneously discovered by Siemens and a partner in the Siemens firm, Hefner von Alteneck, and by Wheatstone and Varley. Since its first appearance the Siemens machine has undergone various improvements. One of the latest types is represented in Fig. 29. It consists of two powerful flat electro-magnets, between whose poles is a rotating armature, not made on the plan of the original shuttle-wound Siemens armature,

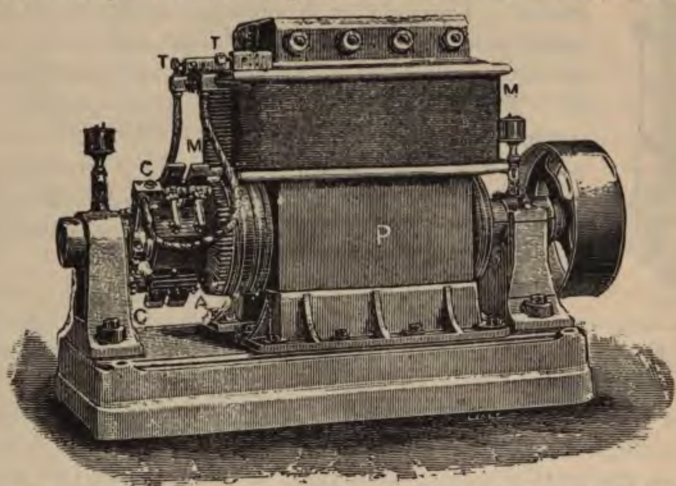

FIG. 29.—Siemens Dynamo (compound-wound). A, armature ; M M, field-magnet coils ; P, iron pole piece attached to near magnet (that of the far magnet cannot be distinguished) ; C C, commutator and collecting brushes ; T T, terminal binding screws.

but on the same general principle as the Gramme ring, which gives its name to another typical dynamo machine.

The principle of this ring may be broadly understood by reference to Fig. 30. Suppose N and S to be the poles of a magnet between which a ring of soft iron, wound over with insulated copper wire, is revolving in the direction indicated by the large inner arrow A. Owing to the action of N and S, magnetism will be induced in the iron ring, and whatever portion of it is for the moment opposite N[1] will possess South-seeking, and that opposite S North-seeking magnetism, so that the ring itself acquires poles which remain sta-

[1] Not exactly opposite, however. The poles of the rotating ring will in each case be a little further forward in the direction of rotation than the poles of the field magnets, owing to the iron requiring time to attain its maximum state of magnetization.

tionary despite its own movement of rotation. In consequence of this, the currents induced by it in its surrounding coil will be such as to flow always in one direction between B, N, B′, and in the opposite direction between B, S, B′, as indicated by the small arrows placed near each convolution of the wire. The result of this will be a rise of potential from B past N to B′ through one half of the ring, and from B past S to B′ through the opposite half of the ring, so that the point of highest potential will always be in that turn of the wire opposite A, and the point of lowest potential in that opposite B. A current will therefore flow through a conductor whose ends are respectively in contact with these points of highest and lowest potential, just as a current will flow through any conductor whose ends are connected to the opposite poles of a galvanic battery. In the actual Gramme machine the ring is not made of one circular bar of soft iron, but of a number of iron wires bent into the required shape, in order to avoid the greater amount of self-induction which would take place in the former case, and which on account of the resistance it entails and the consequent large heat-generation, causes a great waste of energy.[1] The armature coils also are not continuous, as in the figure, but divided into sections, which are connected to each other in series, every one being also connected to a separate copper strip forming a segment of the commutator. The necessary contact between the points of highest and lowest potential and the conducting wires is brought about by means of wire brushes, or in large machines by thin copper plates, which are situated at these points, and which, as the ring revolves, rub against the copper strips already mentioned as forming segments of the commutator. This last is rendered necessary by the fact that a change of direction in the current takes place at B and B′ (see the reversed position of the arrows at these points), so that, unless special means were used to prevent it, the current sent through the outer circuit would be *alternating*. Through the action of the commutator, however, it is rendered *continuous*. The Siemens dynamo represented in Fig. 29 is also a continuous-current machine, but a large and important class of dynamos is made to produce alternating currents, and in these (in

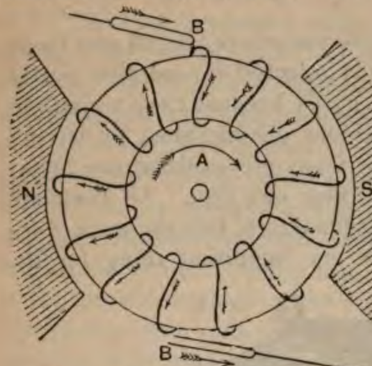

FIG. 30.—To illustrate the principle of the Gramme Ring.

[1] No armature cores, in fact, are solid. They are all made of wires or of thin insulated sheets of iron, to reduce as much as possible what are known as the "eddy" or Foucault currents.

which, of course, no commutator is necessary) the direction of the current is constantly reversed, often many hundred times in a second. Fig. 31 represents a simple form of continuous-current dynamo with a Gramme armature.

It must not be supposed that the dynamos above named are those in exclusive use now. They have been selected for mention partly on account of their historical interest, partly because they are still in wide use and favor. Beside the machines distinguished by having cylindrical and ring-shaped armatures, many are made whose armatures have the form of a drum, others that of a disc. All these are supposed to possess certain technical advantages, but the main principle of all is the same, and that is the one important thing for the

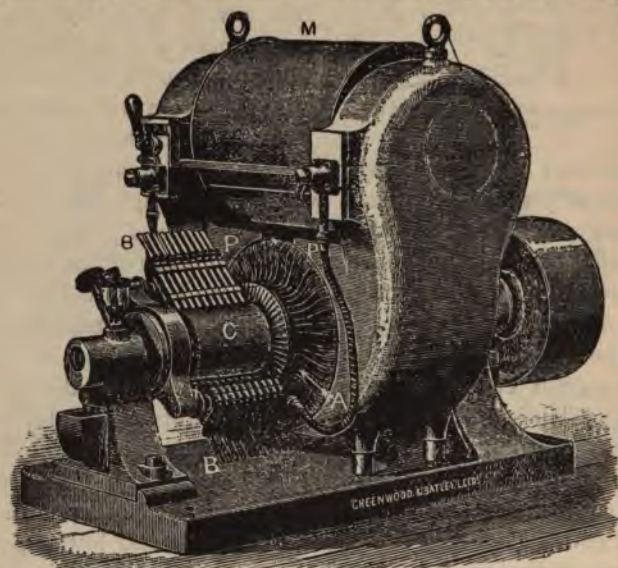

FIG. 31.—Simple form of Dynamo with Gramme Armature. M, coil of field magnet: P P, iron pole pieces; A, armature; C, commutator; B B, collecting brushes.

non-technical reader to grasp. Beyond this he will readily understand that what is wanted to make a good dynamo is a powerful magnetic field, a low resistance in the electric circuit, a great facility of magnetization (high magnetic permeability) in the armature cores and any magnetic portion of the machine, and as little waste of energy as possible through heating. These objects are accomplished in various ways by various makers, and since it is impossible that all can be equally well attended to in all dynamos, the same kind will not be found equally suited for every purpose. Each special class of dynamo will be best adapted to some special kind of work, and experience alone can assign to each that for which it is most fitted. It may be mentioned, however, that the suitability of dynamos to any

particular purpose depends very much on the manner in which the magnet coils are wound. This may be in one of three ways—"series," "shunt," or "compound."

Series-wound dynamos send the whole of their armature current through the field-magnet coils, which are connected in series with the main circuit. These dynamos are used for arc lighting in series, and sometimes for charging accumulators.

In shunt-wound dynamos the terminals of the field-magnet coils and those of the main circuit are separately connected to the collecting brushes, so that the two circuits are in parallel and not in series. The magnet coils being made of very fine wire, offer a much higher resistance than the main circuit, receiving in consequence but a small proportion of the current; they are therefore said to act as a "shunt." Dynamos of this kind are used for charging accumulators, and in some systems of incandescent lighting.

Compound-wound dynamos have the great advantage of being self-regulating, because a constant potential difference is maintained at their terminals, so that the current in the outer circuit is inversely as the resistance. These dynamos are used for arc and incandescent lighting in parallel (viz., in systems where the current does not flow from one lamp to another, but to all separately), and in any case where much regulation is necessary.

The third class of machines to be considered is that of electro-magnetic engines, or, as they are usually called, *electro-motors*. These, as their name indicates, do mechanical work by means of electricity. We have seen that dynamos have mechanical work expended on them in order that they may turn it into electrical energy. In electro-motors the process is reversed; they turn electrical into mechanical energy, and that with far less waste than occurs in the analogous case of a steam-engine turning heat into mechanical energy; so that as a motive power electricity might ere this have remained sole master of the field, had it not been for the great expense till recently entailed by its use.

The constant and persevering efforts of inventors have, therefore, been directed as much to reducing the cost as to improving the construction of dynamos and electro-motors, with how large a measure of success the wide-spread adoption of electric lighting, and to a lesser extent of electric traction, sufficiently prove, while the growing popularity of electrical engineering as a profession shows with what confidence its future is regarded.

It is not necessary to enter into any detailed description of the construction of electro-motors, as they are so similar to continuous-current dynamo machines that any one of these can be used as an electro-motor;[1] only if it is so used, it must be driven by a current from an

[1] Nevertheless it is usually found better in practice to make a machine to be used

external source, not by its own current. The same machine cannot be used at the same time as a producer of both mechanical and electrical energy; it will give out either, but not both, and one must first be given to it. Fig. 32 represents a machine constructed purposely to be used as an electro-motor.

The currents generated by dynamos may be either of very high electro-motive force or of great strength (many ampères), or both, according to the purpose for which they are required and the consequent construction of the machine. For many purposes (such as electric lighting) it is preferable to use currents of a very high electro-motive force. This is much the same as employing a small volume of water at high pressure, instead of a large volume at low pressure; and, in fact, the term "electric pressure" is very frequently used by engineers. It is important to bear in mind, however, that this is merely a convenient mode of expression, and does not assert (as in the case of water) an ascertained fact. Currents of high "electric pressure," *i. e.*, of considerable electro-motive force (1000 volts and upwards), are attended with great risk; for if due precaution is not taken, they are dangerous to life, and should therefore never be carried into private houses, nor is there as a rule any need to do so. For any ordinary illuminating purposes a current of 100 volts is amply sufficient; and though along the main wires from a central lighting station it may be necessary to have a current of 2000 volts or more, by means of transformers this can be reduced on entering a house to 100 volts. Transformers are only an adaptation of induction coils in which the usual process is reversed, and instead of a large current of low electro-motive force inducing a small current of high electro-motive force, the exact opposite takes place. Transformers can, however, only be made use of with alternating currents, for it will be remembered that secondary currents never arise except when the strength of the primary is changing. Consequently, if the latter were continuous, secondary currents and any apparatus depending on them would be impossible. Where transformers are used, the electric-lighting circuit of each house is complete in itself, and is not directly connected with the main circuit, the latter merely inducing in the secondary circuits the currents necessary for their purpose.

FIG. 32.—MOTOR.

as an electro-motor specially for that purpose, as slight differences of construction can then be introduced which render it more efficient.

CHAPTER II.

ELECTRIC LIGHTING.

Electricity a light producer—First exhibition of voltaic arc—In what it consists—Size increases with E. M. F. of current—Vividness—Use in lighthouses—Cause of the light—Unequal consumption of the carbons—Consequent unsteadiness of light—Means of rectification—Variety of arc lamps—Illuminative power—Electric candles—Incandescent light—Its principle—Difficulty originally encountered in construction of incandescent lamps—Obviated by improved vacuum—Description of Edison's and Swan's incandescent lamps—Holders—Generation of electric-lighting currents—Central lighting stations—Street illumination—Indoor illumination—Use of accumulators—High-potential currents necessary in main wires—Importance of careful insulation—English mode—American mode—Imperfection of American installations—Safety of electric lighting if properly carried out—Advantages of electric light—Various appliances.

THE electric spark, the electric glow, and the luminous discharge through rarefied gases, all made known (and lightning did so long before them) that electricity is a light producer. The possibility of using it for ordinary purposes of illumination was not understood, however, till the beginning of the present century, when Sir Humphry Davy first exhibited the "voltaic arc" in public at a meeting of the Royal Society in 1810. He employed for the purpose an exceedingly powerful battery of over 2000 elements, and though the beauty and brilliancy of the light were beyond all question, the expense of its production relegated it for a considerable time after this to the region of experiment only. The arc produced by Davy, and of which so much has been heard since, consists of an intensely vivid band of light passing between two carbon pencils, which form part of a powerful voltaic circuit. These pencils, of which an illustration is given in Fig. 33, are first brought into momentary contact and then drawn a short distance apart. A current of sufficient electro-motive force is able to overleap this gap, but in doing so it has to overcome a very high resistance, and the consequence is an outburst of heat and light of extraordinary intensity. The higher the electro-motive force, the greater may be the distance between the carbon points, and the more vivid of course will be the light. It is too vivid, in fact, for many purposes; it dazzles, and for the interior of most public buildings, churches, hotels, theatres, etc., as well as for private houses, the incandescent mode of lighting, to be presently described, is far preferable. For open air illumination, however, the arc light presents great advantages, not the least of which is its comparative

FIG. 33.—Carbon Pencils used for the production of the arc light. the positive pencil showing the concave form assumed owing to its more rapid consumption.

inexpensiveness; and it is unrivaled in one department of the highest importance, viz., that of lighthouses, where its object is not so much to render other things visible as to be seen itself; it was in fact for them that it was first brought into use. In the search-lights employed for naval and military purposes, its great intensity renders it also specially suitable.

The main cause of the light appears to be the incandescence of minute particles of carbon, which are carried in two incessant streams between the carbon pencils, the principal direction being always from positive to negative. On account of the great affinity of carbon at a high temperature for oxygen, combustion of the pencils takes place even when they are exposed to rarefied air, the positive carbon consuming nearly twice as fast as the negative.[1] Consequently the distance between the two pencils is continually increasing, and unless means of rectification are used, soon becomes too great to allow the current to overleap it, so that the light, after becoming fainter and fainter, goes out altogether. Numerous ingenious automatic contrivances have been devised to obviate this difficulty, and keep the carbons at an equal distance apart; and these, combined with the great steadiness of current which is attainable by the use of the modern compound-wound dynamos, have almost completely done away with the flickering and inconstancy of the earlier arc lights. If, therefore, such inconveniences are suffered from in modern days, it is because the installations are in some way less perfect than they could be.

The variety of arc lamps is very great, but their principle having been described, it is needless to go into technical details, which would be wearisome to the general reader. Suffice it to say that the principal aim of inventors is to increase the steadiness of the light by keeping the distance between the pencils as constant as possible, and by using in their construction the purest carbon obtainable. The illuminative power of an arc lamp depends of course on the size of the arc, and this partly on the quantity of current, so that for lamps which are intended to light up a large area, currents of many ampères are needed.

Electric candles, which are a form of arc lamp, must not go unmentioned. The first was the Jablockoff, so called from the name of its inventor. It consists of two perpendicular rods of carbon, united at the top by a very thin bridge of the same substance, below which they are divided by a layer of some insulating material, usually plaster of Paris. When the current passes, the carbon bridge is rapidly consumed by the intense heat developed, and a voltaic arc takes its place,

[1] It must not be supposed, however, that combustion is the cause of the light, as in an ordinary oil or gas lamp, for the arc light can be quite satisfactorily produced in a vacuum or under water.

which melts the insulating material as the carbons gradually burn away. In order that their consumption may be equal, alternating currents are used, so that the same carbon is alternatively positive and negative. The Jablockoff candle is equal in illuminative power to ten, twenty, one hundred or more ordinary candles, according to its size. It was at one time in great demand, especially in France, but was never found altogether satisfactory, and has therefore almost fallen into disuse. Later and better forms of electric candle have been devised, using air as the insulating layer, and with other improvements; but they are neither so simple as the regulated arc lamp, nor do they give so high a proportion of light for the current expended on them, and they are therefore not much employed.

On account of the unsteadiness and too great brilliancy of the arc lamps, electric lighting for domestic and most indoor purposes would never have become general had there not existed another and in this respect more satisfactory method, known as the *incandescent*. In this no gap is formed in the circuit, but it includes substances of very high resistance (such as carbon or platinum), which are raised to a white heat by the passage of the current. Almost every reader is acquainted with the beautiful little lamps known by the names of Swan and Edison, whose light for all ordinary purposes leaves nothing to be desired either in softness or brilliancy, yet hardly ten years have elapsed since their first appearance. The possibility of "incandescent" electric lamps was indeed known long before this, but an insuperable difficulty seemed to lie in the way of their construction, for a material was needed combining two qualifications which had never been found united in the same substance. The first was that it should not, when raised to a high temperature, have an affinity for oxygen; and the second, that under the same circumstances it should not melt. Carbon possessed the latter of these requirements, and platinum the former; but no vacuum had ever been made sufficiently perfect to render carbon incombustible, and platinum could not of course be induced to raise its melting-point, already higher than that of any other metal. The perfecting of the mercurial air-pump at length rendered it possible to produce a degree of exhaustion, in which carbon remained incombustible for want of oxygen to combine with, and from that moment the future of the incandescent lamps was secured. Inventors by the score sprang into the field, each with a lamp which some special qualification was supposed to render superior to all others, but the most successful competitors were Swan in England, and Edison in America, soon followed by Lane Fox in the former, and Maxim in the latter country.

The principle of the incandescent lamps is the same, whatever differences of detail there may be in their construction. It consists in raising a thin carbon filament, enclosed in a glass vessel exhausted to the pitch of about the millionth of an atmosphere, to a state of incandescence,

by the passage through it of an electric current. The carbon filaments are made of different materials by different constructors. Edison uses bamboo fibres, 0.04 inch in diameter and about five inches in length; Swan selected cotton thread, which he soaked in sulphuric acid, thus transforming it into a species of parchment; and this preparation is adopted by the Edison-Swan Company. Edison's bamboo fibres are carbonized by being placed in U-shaped molds and baked in ovens. Swan's thread fibres, after being treated with the sulphuric acid, are bent into the desired form, and enclosed in hermetically-sealed crucibles filled with coal-dust, which are subjected to the requisite heat. These carbon filaments are fastened to platinum wires, which are fused into exhausted glass vessels, and their free ends connected by appropriate adjustments to the wire conveying the current. In order to ensure equality of resistance, the carbon filaments are made of exactly the same thickness throughout, which is secured by placing the carbon filaments in a hydro-carbon atmosphere, and passing a current through them till they glow. A deposit of carbon on the filaments is the result, the deposit being thickest where the carbons are thinnest, and therefore hottest. This operation is called "flashing." At the points of junction with the platinum wires, however, a great increase of thickness is necessary in order to prevent the melting of the platinum by the intense heat developed.[1] Fig. 34 represents an Edison incandescent lamp.

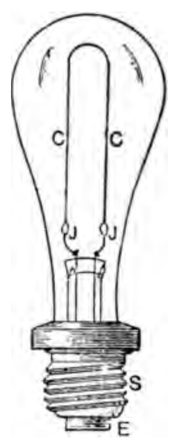

FIG. 34. — Edison's Incandescent Lamp. C C, carbon filament; J J, junctions of the carbon filament with platinum wires; *p p*, platinum wires by means of which current is conveyed to the carbon filament; S E, metallic screw and end forming the terminals of the lamp, contact being automatically made with the similar parts of the socket into which the lamp is fitted.

All incandescent lamps need special holders by whose means the necessary connection with the conducting wire can be set up and maintained.

The currents for electric-lighting purposes are generated by dynamos, which are driven by steam or gas engines, or when practicable by water power. For every eight or ten lamps of sixteen candle power each, current is required which necessitates an expenditure of mechanical work equivalent to one indicated horse power, so that the dynamos and engines must be in proportion to the amount of lighting to be done and the consequent current needed.

[1] It is erroneous to suppose that the electric light is unaccompanied by heat. That of the voltaic arc is the most intense known, and we have seen that even platinum is unable to withstand the high temperature to which the passage of the electric current raises it. Nevertheless, on account of the small volume of the arc, and of the incandescent carbon filaments, they give out, though intensely hot themselves, a very minute amount of heat compared to that from gas and candle flames for the same amount of light.

The arc lamps used in street lighting may be connected to the main circuit either in parallel or in series, according to the system employed. If they are in series, the current passes through each one in succession, and, unless special provision is made, they must all be turned on or put out together. In some systems, however, notably the Thomson-

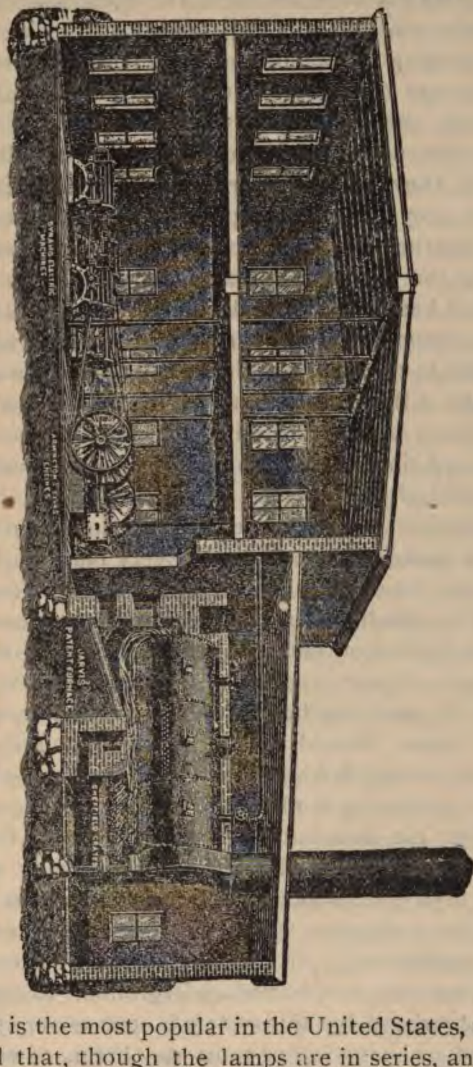

Fig. 35.—Model Electric-Lighting Station on the Thomson-Houston System.

Houston, which is the most popular in the United States, the machines are so regulated that, though the lamps are in series, any one can be cut out of circuit, if desired, by means of a "switch," the amount of power consumed being in proportion to the number of lamps maintained. Fig. 35 shows a model electric-lighting station on the Thomson-Houston system.

The circuits which supply domestic, and, in fact, all indoor

illumination, are often, by means of transformers, or of secondary batteries, kept distinct from the main circuit, the latter being merely used to feed them. In the case of transformers this is done by induction, as was described in Chapter I., the apparatus being carefully enclosed in a locked receptacle, so that no inmate of the house in which it is placed can have access to the dangerous currents. In the case of secondary batteries, or *accumulators*, as they are very frequently called, the charging is done by the main circuit current, from which they are afterward disconnected and made to do their own work, to be reconnected and recharged when necessary. There are two objections to the use of accumulators, however—their cost is considerable, and they constantly require skilled attention. On this account, when they are used to supply town dwelling-houses, a number are placed together in a sub-lighting station, and each one is connected during the time the current is required to the house which it feeds. When it has to be charged, it is joined in series with the other accumulators belonging to the same group as itself, and this group is then connected to the main circuit for the requisite number of hours.[1] The advantage of this arrangement is that the dynamos which supply the main currents can be utilized to charge the accumulators during the daytime, and since these then feed their own circuits, the installation at the central station may be much smaller than if it had to provide directly all the current required during the night hours, as is the case when transformers are used. Every lamp for indoor illumination can be, and usually is, supplied with a separate connection to the conducting wire, which can be made or broken at pleasure, so that the lamp may be lighted or put out independently of any other in the same building. A great number also are provided with safety fuses, viz., a piece of wire attached to the lamp, and through which the current must pass. Should the latter attain an undue strength, the fuse melts, the circuit is broken, and the lamp goes out, so that all danger from overheating is obviated.

In order that the distribution of electric energy from the central lighting station may be carried out as economically as possible, currents of very high electro-motive force (usually about 2,000 volts) are conveyed by the main wires, which it is therefore necessary to insulate in the most careful way. In England they are surrounded by layers of insulating material, and buried underground. In America they are often carried overhead, but this system is open to very great objection, as a high wind or heavy fall of snow may break down the wires, and they are then exceedingly dangerous, both on account of the high

[1] Of course accumulators cannot be charged except by continuous-current dynamos, as the chemical decomposition necessary to the storage of electric energy could not be carried on with alternating currents, which would undo the work as fast as it was accomplished.

potential currents they convey, and of their own weight. It is to be observed, that though electric lighting is far more extensively used in America than in England and Europe generally, the technical perfection of the installations is not so good. Insulation is not sufficiently attended to,[1] the neighborhood of gas-pipes and mains to the wires is not avoided as it should be; so that in case of overheating of the latter, danger of explosion occurs; and the system of overhead wires, unsightly to the last degree, gives rise to inconvenience and peril, which till lately met with less consideration than should have been the case. In New York, however, a regular rebellion has taken place against the overhead system, the wires have been hewn down in all parts of the city, and their place is being supplied as fast as possible by underground cables.[2] So many accounts of fatal accidents (numbers of which are untrue) from electric-lighting currents have been telegraphed across the Atlantic, that timid persons may well shrink from the idea of seeing them come into general use in England. There is no real occasion for alarm, however. If the conducting wires are thoroughly insulated, so as to render the touching and handling of them impossible, very carefully joined where joins are necessary, and thick enough not to be overheated by the strongest current they would ever be called upon to convey, no possible danger can occur. If these precautions are neglected, the consequences may be disastrous, though not more so than if due care is not taken with those equally perilous agents, gas and steam. An electric light installation set up by competent electrical engineers, allowed to provide all those safeguards which they know to be necessary, is perfectly harmless; but if cheapness is made the first desideratum, and bad workmen and bad materials are employed, the result is as unsatisfactory and dangerous as a similar mode of proceeding would be if followed by gas and railway companies.

The advantages of the electric over other kinds of artificial light are in many respects very great. In the first place, it is much healthier; for it does not, as they do, take up oxygen and give out carbonic acid gas. Then, it does not perceptibly raise the temperature of an enclosed space, so that a room or building lighted by it does not become filled with overheated air. Again, owing to its near approach to the composition of sunlight, colors are clearly distinguishable by it, which are confused with one another or altered in hue by gas or candle-light; and for the same reason, photographic and other chemical work can be carried on by its means when they would otherwise be impossible. The electric light is, in fact, particularly rich in

[1] It is just to say, however, that owing to the much greater dryness of the climate, insulation is far more easily carried out in America than in England, and a system which would be dangerous in the latter country might be perfectly safe in the former.

[2] January, 1890.

chemical rays; and the arc light, owing to the preponderance of violet in its spectrum, gives a cold and rather ghastly appearance to persons and things. This is not the case with the incandescent lamps; and, in fact, when sunlight and any kind of electric light are seen at the same time, the latter is found to have by comparison a reddish hue. The weird effect of the arc light is probably in great part due to our being accustomed to the very red tint of gas; and, of course, where the two illuminants are seen close together, as frequently happens in London, the result is exceedingly unpleasant.

Besides its extensive adoption on land and for lighthouses, where its superiority over any other kind of illuminant is incalculable, the electric light is also much used now on board ship, as well for ordinary purposes as for signaling; and it is of interest to note that by its means the Suez Canal has been rendered navigable by night, its passage during the hours of darkness being permitted to all vessels carrying electric search-lights, arranged according to the regulations laid down by the Canal Company. The use of electric search-lights on board warships has already been referred to, and their importance can hardly be over-estimated now it is acknowledged that nets are of little if any protection against torpedoes, so that the only safety from these formidable engines of destruction lies in being aware of their approach. This can only be ensured at night by throwing powerful streams of light in every direction from which danger is to be apprehended, and the intensity of the arc light makes it specially suitable for this purpose, rendering the detection of torpedo-boats a matter of comparative ease.

Among the minor uses to which the electric light has been put, the production of very beautiful scenic effects in theatres may be mentioned; and it has even been made to contribute to the personal adornment of the actors. "Electric hairpins" are described in "Electricity in the Service of Man."[1] They are simply miniature glow lamps arranged so as to simulate gems of various colors, and supplied with the necessary current by a tiny battery enclosed in a gutta-percha box, small enough to be concealed in the hair or head-dress. Another very ingenious contrivance is mentioned in the same work, and consists of an apparatus enabling a faint light like that of the will-o'-the-wisp to play about the heads of those wearing it. The frequent variations of intensity which are necessary in theatrical lights, render indispensable contrivances enabling any particular lamp, or whole series of lamps, to be put in and out of circuit as desired; and, in fact, such arrangements are required in all indoor illumination, as the number of lamps in use in any building is constantly altering. If many lamps are put out of circuit at the same time, it is necessary, unless compound-wound, *i. e.*, constant potential-

[1] P. 562.

difference, dynamos are supplying the current, to increase the resistance encountered, as the current would otherwise be too powerful for the remaining lamps. To accomplish this, arrangements are made by which resistance-boards or coils can be included or cut out of circuit at will. The latter are merely wire coils usually made of German silver; the former consist of a number of parallel carbon rods fixed on a wooden board, any or all of which can be included in circuit as desired.

A very curious appliance of the electric light is mentioned in *The Electrician* for January 10, 1890, viz., its being used to lure fishes and submarine animals into a trap employed in the deep-sea investigations undertaken by the Prince of Monaco. The light and the battery supplying it were placed in a wire trap, and in order to keep the box in which the battery was enclosed from being crushed by the enormous pressure of water, it was connected with an air balloon in such a way that air could pass from one to the other. As the pressure on the balloon increased in its descent through the water, air was forced from it into the box, thus providing the interior of the latter with an equal and contrary pressure to that exerted on its exterior, the balloon itself gradually diminishing in size till it was reduced to a fraction of its original volume, and expanding again when the apparatus was raised and the pressure of water decreased. The experiment was so successful that the Prince hopes on his next expedition to obtain photographs of the ocean bed by means of the electric light.

For purposes of electric lighting and transmission of power, it is obviously necessary that both supplier and consumer should be able to gauge, with fair exactitude, what amount of electric energy is used; but the measurement cannot be accomplished in so simple and certain a way as the measurement of gas consumption, for instance. The latter depends upon quantity only, but the measurement of electrical energy depends upon the electro-motive force (or pressure), as well as on the strength of current. If the former were to fall below its right value, the consumer would not be getting his due proportion of energy, though the current strength might be fully maintained. The meter employed, therefore, ought to be a *volt-meter* or measurer of electro-motive force, as well as an ampère or *am-meter*, measurer of current strength. It is not easy to combine these two requisites in a simple and efficient form, and many inventors have employed their ingenuity in this direction, without as yet obtaining a perfectly satisfactory result. The best appears to be given by the clock-meter of Professors Ayrton and Perry, whose most important constituent is a good clock, the works of which are electrically connected to the wires conveying current to and from the house, in such a way as to be affected both by its pressure and strength. The clock consequently

loses in exact proportion to the amount of energy consumed. If, however, a constant electric pressure between the house mains can be secured, it is sufficient to measure only the quantity of current that passes.

CHAPTER III.

TRANSMISSION OF POWER BY ELECTRICITY.

Definition of power—Units of power—Various agents for the transmission of power—Its importance—Loss incurred—Advantages of electricity as a transmitter of power—Its probable universal adoption—Requisites for the transmission of power by electricity—Electric railways—Telpherage—Attempts to utilize electricity for road traffic—Other applications—Electric launches.

BY the term "power" engineers understand the rate of doing work. The transmission of power therefore means not simply the transmission of work, but of a given amount of work in a given time. The ordinary unit of work in England is the *foot pound*, viz., the amount of work done in raising one pound to the height of one foot. For engineering purposes horse-power, which is equivalent to 33,000 foot pounds per minute, is often used as the unit of power; and in electrical engineering the unit of power is the Watt, which equals 44¼ foot pounds per minute, so that 746 Watts are equivalent to one horse-power.[1]

Power may be transmitted by various agents. We may pull a handle connected to a bell wire, and thus ring a bell in a distant room; the wire is here the transmitter of power. Or there may be no bell wire, but by pulling the handle we may cause the compression or rarefaction of air in a tube, at the other end of which the bell will ring. In this case the transmitter of power is the air. Or the bell may be an "electric bell," and by the pressure of our hand on a button in the wall we may start an electric current, by means of which the ringing is accomplished; electricity then being the transmitter of power. It is the transmitter only, however, not the source. That, in each of the three cases mentioned, is the human hand, whose action in pulling or pressing the bell handle, originates the power transmitted by the wire, the air, or the electric current.

Even from such a trivial example as the ringing of a bell, it is easy to see what importance attaches to the transmission of

[1] Electrically defined, the Watt is the power developed in a circuit through which a current of one ampère is flowing, and which has a potential difference of one volt between its ends.

power, and what saving of time and labor it may enable us to effect. Because the mechanical action of pulling or pressing a bell-handle can be transmitted to a distance, a slight exertion and a small bell will suffice; but if we could only ring the bell at the spot where we ourselves might be, a much larger bell and far greater exertion would be necessary in order to attract the attention of those at a distance.

In all transmission of power some loss occurs. We never get back exactly the amount of power originally expended, and where the distance is great the loss is often very considerable. It is less where electricity is employed than in any other case, however, and consequently now that dynamos and electro-motors are so much less costly of construction than they were a few years ago, electricity bids fair to become the cheapest, as well as the most rapid, cleanest and most easily controlled transmitter of power known. It has not, indeed, yet been applied to great distances and large power; but whatever initial difficulties there may be in thus utilizing it, they are not of such a formidable nature as to prevent, or even long retard, its widespread adoption; and not scientists and electrical engineers only, but the foremost statesman in England [1] has ventured to look forward to the time when noisy and crowded factories will be abolished, and each workman supplied at his own house with the power necessary for his work, distributed from a central station as electric-lighting currents now are. In fact, with very little increase of cost and material, the same station would serve both purposes. The currents are not wanted for lighting during the daytime; and though, where accumulators are used, they must be charged, this would not occupy all the dynamos at a central station, nor any of them during a whole day, so that, at no very distant future, we may contemplate the establishment of centres which shall supply each household with light during the hours of darkness, and with power during the day. This system is already extensively adopted in America, to supply workshops where only small power is required, such as those of tailors, shoemakers, watchmakers, etc., but it has not yet been attempted on a large scale.

The requisites for electrical transmission of power are—

1. Mechanical power of some kind to drive the dynamos.[2]
2. The dynamos or current-generators themselves.
3. An electro-motor or motors, placed where the supply of power is required.
4. An electrical connection between the dynamos and the electro-

[1] Lord Salisbury in his speech at the First Dinner of the Institute of Electrical Engineers.

[2] It is not intended to state that the transmission of power by electricity can only take place by means of currents generated by dynamos. Batteries may be used; but for reasons already pointed out they are unsuitable, except when (as in telegraphy) the power to be transmitted is very small.

motors, unless accumulators are used, when such connection is of course unnecessary, and the dynamos are employed for charging.

The driving of the dynamos is generally accomplished either by water-power or steam. Wherever the former is available it is the best and most economical to use, and the continual regret of electrical engineers is the amount of energy running to waste in our streams and rivers, their dream for the future being that as electrical transmission of power becomes better understood and more easily available over long distances the water-power of every country may be found sufficient for its needs. Dynamos and electro-motors have been described in a previous chapter, and, with regard to the connection between the two, it varies according to the nature of the work to be performed, and with other local and technical causes.

The most important use to which electricity as a motive-power has been put is that of traction. Electric railways, or, more correctly speaking, tramways, as they are used only over short distances and for light traffic, are becoming well known, though not yet common. The motors are usually placed under the floor of the cars, and are supplied with current either through the rails on which the cars run, or by separate underground conductors, or by overhead conductors, as in Fig. 36; or they may be driven by accumulators, which in some

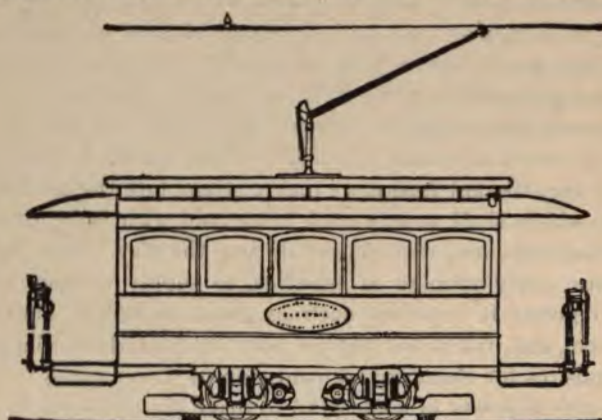

FIG. 36.—Electric Tramcar supplied with current by overhead conductors.

ways simplifies matters, as the rails need not then be insulated, and each car can be independent of its fellows. In other respects this system has disadvantages; the weight of the accumulators, which of course must be carried by the cars, being one, and the double transformation of energy they entail being another, as more waste is thereby necessitated.[1]

[1] Where accumulators are employed, mechanical energy (that used to turn the dynamo armatures) must first be converted into electrical energy, then the latter changed in the accumulator to stored-up chemical energy, which on being liberated is

The telpherage system, formerly used for the transport of goods only, but now beginning to be employed for passengers also, is specially suitable and economical for hilly country, and was introduced by Professors Ayrton and Perry, and the late Professor Fleeming Jenkin. In this system the traffic is carried on overhead, the conductors and trucks being suspended from poles erected about fifty yards apart. The conductors sometimes consist of two steel cables fixed one above the other, the trucks being suspended between them, and the upper cable bearing most of the weight. More usually, however, there is only one steel cable (as in the passenger telpher line at the Edinburgh Exhibition), by which the whole weight is supported. The trucks are provided with wheels through which, as they run along the conductors, the necessary current is supplied.

Attempts have been made to utilize electricity for ordinary street traffic, as well as for railways. In this case the motors which propel the vehicles are of course driven by accumulators, and success has been attained for short distances and light weights;[1] but for long distances, difficulties occur through the necessity of exchanging the exhausted accumulators for fresh ones; and when the cart or carriage is heavy, it is impossible to stop it with the rapidity often necessary in crowded streets. This difficulty arises from the increase of weight occasioned by the use of large accumulators, which gives too great a momentum to the vehicle.

Electricity has been made useful for locomotion in mines, for boring rocks, for lifts, for cranes, for brakes (the Westinghouse brake being familiar, at least by name, to all readers), and for driving machinery in factories.

Electrically-propelled ships have not been attempted on a large scale, but many electric launches are made, and found to answer exceedingly well. Their chief inconvenience lies in the fact that owing to their motors being driven by accumulators, they cannot go far from the charging station, unless indeed (as has been done on the Thames) sub-stations are placed at intervals on the line of route, so that exhausted accumulators can be replaced by fresh ones when necessary. The most recent application of electricity to naval purposes has been independently made by the French and Belgians, in submarine electric launches or torpedo boats, recalling on a small scale the marvelous vessel in Jules Verne's "Twenty Thousand Leagues under the Sea."

transformed once more into electrical energy, and then through the electro-motor back into mechanical energy. Where the dynamos supply the motors directly two transformations only take place, from mechanical into electrical energy in the dynamo, and from electrical into mechanical in the motor.

[1] An electric dogcart, made for the Sultan of Turkey in 1888, gave its imperial owner so much satisfaction that he has since ordered another.

The various uses to which electricity as a motive power has been put, have now been enumerated, but there is one to which neither it nor any of its rivals has yet been successfully applied, but which, nevertheless, we can hardly help regarding as probably one of its important functions in the future—this is aërial navigation. If our descendants are to travel in balloons, it will certainly be through the agency of electricity; and as the various electrical engines become more and more perfected, we can hardly doubt that in time a sufficiently light means of storing electric energy will be devised to make that dream of past ages—a flying machine—an actual reality.

CHAPTER IV.

THE ELECTRIC TELEGRAPH.

Early suggestions for using electricity and magnetism as a means of communication—Volta's and Œrsted's discoveries the foundation of modern telegraphy—Number of inventors who have contributed to its perfection—Wheatstone and Cooke's telegraph—Discovery of the "earth-circuit"—Introduction of the "translation" system—Recording and non-recording instruments—Morse's services to telegraphy—His embosser and ink-writer—The Morse key—Speed of transmission of messages—Hughes printing telegraph—The Morse sounder—Submarine signaling—The syphon recorder—Manner of conveying and insulating overland wires—Submarine cables—Duplex and quadruplex telegraphy—Telegraphic currents generated by batteries.

IT seems that the first really practical suggestion for using electricity as a means of communication, was made by the anonymous author of a letter to the *Scots Magazine* in 1753. The suggested apparatus, though cumbrous and complicated according to modern ideas, was very ingenious, but there is no record of its having been actually used. The writer, and such of his readers as took any interest in the subject, were doubtless of opinion that at any rate the idea was an entirely novel one, but in this they were to some extent mistaken. Though nothing was known about "current" electricity until the end of the eighteenth century, there had been vague ideas long before then that magnetism might be in some way utilized for purposes of communication. About 1750 a certain Joseph Glanvil, rector of Bath, who, we are informed, was a "learned writer upon abstruse and mystical subjects," wrote as follows in a treatise entitled "The Vanity of Dogmatizing," and in which he speaks of "supposed impossibilities which may not be so."

"That men should confer at very distant removes by an extemporary intercourse is a reputed impossibility; but there are yet some hints in natural operations that give us probability that 'tis feasible, and may be compassed without unwarrantable assistance from demoniack correspondence. That a couple of needles equally touched by the same magnet, being set in two dials exactly proportioned to each other, and circumscribed by the letters of the alphabet, may effect this 'magnale' (*i. e.*, important result), hath considerable authorities to avouch it. The manner of it is thus represented. Let the friends that would communicate take each a dial, and having appointed a time for their sympathetic conference, let one move his impregnate needle to any letter in the alphabet, and its affected fellow will precisely respect the same. So that would I know what my friend would acquaint me with, 'tis but observing the letters that are pointed at by my needle, and in their order transcribing them from their sympathized index as its motion directs, and I may be assured that my friend described the same with his, and that the words on my paper are of his inditing. Now, though there will be some ill contrivance in a circumstance of this invention, in that the thus impregnate needles will not move to, but avert from each other (as ingenious Dr. Browne hath observed), yet this cannot prejudice the main design of this way of secret conveyance; since it is but treading counter to the magnetic informer, and noting the letter which is most distant in the abecedarian circle from that which the needle turns to, and the case is not altered. Now, though this desirable effect possibly may not yet answer the expectations of inquisitive experiment, yet 'tis no despicable item, that by some other such way of magnetic efficiency it may hereafter with success be attempted, when magical history shall be enlarged by riper inspections; and 'tis not unlikely but that present discoveries might be improved to the performance." [1]

Could Joseph Glanvil's spirit revisit us now, he would see his expectations more than fulfilled, though it has not been by "riper inspections of magical history," but of natural science, that the "reputed impossibility" has become possible. Forty years after the treatise "On the Vanity of Dogmatizing" saw the light Volta had made his first battery, and twenty years later still came the announcement of Œrsted's famous experiments on the action of electric currents on the magnetic needle. These two discoveries are the foundation-stones of our modern system of telegraphy, which would be impossible without a steady current, as distinguished from the momentary rush of a discharge, and to which the deflections of the magnetic needle, under

[1] The above curious passage is quoted from a letter by the Rev. Canon Jackson of Leigh-de-la-Mere, Chippenham, the well-known antiquarian, to the *Bath Chronicle* in October, 1890.

the influence of electric currents, contributed a code of signals far superior to any which had previously been attempted with electricity.

So many scientific inventors have aided in bringing the electric telegraph to its present degree of perfection, that it would be impossible in the short compass of a chapter of the present volume even to name them all. The first really workable telegraph introduced into England was that of Wheatstone and Cooke, who at first employed five needles and as many wires to transmit their signals, but soon finding the cost and inconvenience of this method rendered its general adoption impracticable, they reduced the number of needles to two and finally to one, whose deflections to the right and left were so combined as to represent all the letters of the alphabet. In all the earlier telegraphic circuits it was considered necessary to have a return wire, but in 1838 Steinheil discovered that this could be dispensed with, and that if the two ends of the conducting wire were connected to earth, one at the sending, the other at the receiving station, the earth itself would play the part of the return wire. This discovery of the "earth circuit" was of the greatest practical importance, owing to the reduction in cost which it brought about.

Another very important improvement in the construction of electric telegraphs, is the system of "translation," which was introduced by an Englishman, Edward Davy. The principle consists simply in cutting up one long circuit into a number of short ones, which can be automatically connected whenever a signal is transmitted. The advantage of this system is, that even on a long circuit a weak current may be employed, as it will only have a comparatively short distance to traverse before its work is taken up by another.

The telegraphic instruments in modern use may be divided into two classes, recording and non-recording. To the former (whose signals are merely momentary and leave no after-traces) belong the needle and dial telegraphs and the sounders. To the latter belong the embossers, ink-writers, and type-writers. In international telegraphy and in the English Post-Office, Morse's instruments, of which some are recording and some non-recording, are almost exclusively used, and a slight description of them will therefore be given. Their inventor, Morse, who received considerable sums of money from various nations, in recognition of his services to international telegraphy, was an American, and his first experiments in the direction in which he afterward became so famous, were made as early as 1834, when he had already twice visited Europe. He labored at first under the disadvantage of very inadequate electrical knowledge, and, indeed, his mind was originally turned to what became his life-work by the accidental acquaintance made on one of his return voyages to America, with a fellow-traveller, Professor Jackson, of Boston, who was engaged on electrical experiments. At a later period Morse was in-

debted to his subsequent partner, Leonard Gale, for various suggestions as to the chemical part of his work.

Morse's embossing instrument leaves a permanent record of the message sent by indentations on a slip of paper. These are made by means of a small electro-magnet with a movable armature, to which is attached a hard-pointed piece of metal. Whenever a current passes through the instrument the armature and stylus are drawn forward, and the latter brought into contact with a slip of paper, unrolled and passed on by clockwork. When the current is interrupted, the armature and stylus return to their former position, to be again drawn forward as soon as a current is set going. In this way a series of scratches is made on the paper, the marks being longer or shorter according to the length of contact, and divided by spaces varying with the time of interruption of the current. The short marks are known as dots, and the longer ones as dashes, and by suitable combinations of them all the letters of the alphabet, the numerals, punctuations, and various signs are expressed in a system of signals, known as the Morse code, which is now almost universally adopted in Europe and America.[1] Morse's ink-writer, which is in most general use, is on the same plan as the embosser, but the place of the stylus is taken by a small disc kept constantly wetted with ink, by means of a suitable mechanical arrangement, so that ink-marks instead of scratches are impressed on the paper.

The incessant interruptions of current necessary in the Morse and in all telegraphic instruments, are brought about by means of a commutator or key, by which the operator closes and opens circuit at will. The Morse key is simply a brass lever kept in position by a spring S, as shown in Fig. 37. When the operator presses down the button B, he

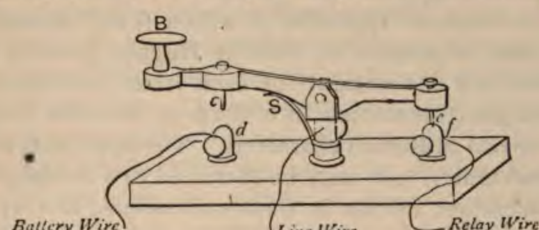

FIG. 37.—The Morse Key.

causes *c d* to come into contact, and by their means sends a current from the battery into the line wire. When B is not pressed down, *e f* are in contact as in the figure, and a current coming along the line passes round the relay electro-magnet (see Fig. 38) and works the relay tongue (*a*). This closes the circuit of a local battery, which sends a sufficiently strong current round the electro-magnets of the receiving

[1] The Morse code is used in the needle telegraphs also, an inflection to the left representing a dot, and one to the right a dash.

instrument to pull down the lever of the embosser or ink writer, an operation requiring too much force to be accomplished by the weak current which comes along the line. Polarized relays, *i. e.*, relays in which the core of the electro-magnet is formed of a steel magnet whose poles are not reversed by change of direction in the current, are almost always used.

It is evident that the speed of transmission of messages must depend to a great extent on the number of currents required to form the different letters. In the Morse system about three currents are

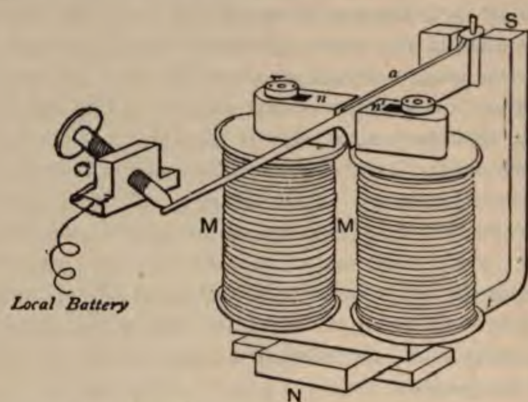

FIG. 38.—Polarized Relay. S N, permanent steel magnet whose North-seeking pole is bifurcated, its branches making the core of the electro-magnet M M, and terminating in the pieces *n* and *n'*, between which works the soft-iron armature or tongue *a*; connection is made with the local battery by means of the contact-piece C whenever a current passes through the coils M M.

wanted on an average for each letter. Inventors have therefore endeavored to construct apparatus in which fewer should be necessary. The most successful of these is Hughes' printing telegraph, which requires only one current for each letter, and which can also print its messages (transmitted in a third of the time occupied by a Morse instrument) in Roman characters. The apparatus is, however, so complicated that it can only be entrusted to a thoroughly trained and skilled operator; its use is therefore confined to very important telegraphic lines.

The Morse sounder (for which the Morse key is used as a commutator) is a non-recording instrument, and its signals appeal to the ear instead of to the eye. Its simplest form is one in which a small electro-magnet is supplied with an armature in the form of a lever, the free end of which works between two stops, and taps against one when the current starts, and against the other when it ceases. The intervals between the taps are made longer or shorter according to whether a dash or a dot is to be represented, a short pause corresponding to a dot and a longer one to a dash. It is evident that in

this system mistakes are more liable to be made in a message than where reference can be had to recorded signs. Nevertheless, with skilled operators errors very rarely occur, and the greater rapidity with which transcription can take place offers an advantage which in America, at all events, outweighs other considerations, for the sounder is used almost to the exclusion of any other instrument. It is also widely adopted in India.

Submarine signaling, where the distance is great, requires special and very delicate instruments, the currents being too weak to work satisfactorily with any ordinary apparatus.[1] For a considerable time Sir William Thomson's mirror galvanometer (described in Chapter iii, of Part III, p. 87) was almost exclusively used, but owing to the great fatigue to the eyes incurred by watching the movements of the little spot of light for a long time together, this instrument has now been to a great extent superseded for signaling purposes by another invention from the same high quarter, the syphon recorder, which by means of a flat coil of wire in circuit with the line, and suspended between two powerful electro-magnets, communicates motions to a very fine glass syphon, dipping into an insulated metal ink vessel, and having its other end adjusted over a paper strip. When a message is to be recorded, the vessel of ink is connected with a charged conductor, and the result is to force the drops of ink on to the paper, unrolled by clockwork, as in the Morse instruments. The mechanism is so arranged that when a current is passing, the point of the syphon moves alternately to one side and the other of the centre of the paper, and thus two lines of ink spots are made, one of which corresponds to the dots and the other to the dashes of the Morse code.

It is hardly necessary to describe the mode in which ordinary overland telegraph wires are conveyed from place to place. We are but too familiar with the gaunt wooden posts, and the wire lines suspended from them, which make our railroads even more hideous than they would otherwise be. The wires thus employed are made of galvanized iron (iron coated with zinc), and every post carries insulating supports through which the wires pass. In England, and Europe generally, overhead wires are replaced in large towns by an underground system, in which a number of wires are enclosed in iron or earthenware pipes and buried in the soil. These wires are made of copper, and each one is insulated by a gutta-percha covering. But for the greater cost and small mechanical strength of copper wires, they would always be preferable to iron for telegraphic purposes, owing to their much lower specific resistance and their greater power of withstanding exposure to the weather. If the wires break, come into contact with other wires, or with conductors connected to the

[1] The current given out by the Atlantic cable, when twenty-five words per minute are being transmitted, is one-millionth of an ampère.

earth, there ensue total or partial interruptions of the currents they convey, technically known as "faults." Various means are taken to prevent these and to ensure their speedy remedy when they do occur. The most important precautions are the thorough insulation of the wires, the frequent introduction of "testing-boxes" along the circuit, which enable the real position of the fault to be speedily discovered, and (in the case of overhead wires) the metallic connection of each one of the insulating supports with the earth. This obviates the danger of one wire leaking into another (which might otherwise frequently occur in wet weather), by supplying an easier and more direct path to the earth for the leaking current. These earth connections of the insulators also serve the important purpose of lightning conductors, which are indispensable both along the line and at the signal stations, as without them the lightning discharge might travel along the wires, not only interrupting the messages, but destroying the telegraphic instruments, and injuring or even killing the operators. Such accidents have more than once happened. In wires carried underground another difficulty has to be contended against, viz., the taking up by the wires of a static charge of opposite sign to that of the surrounding earth, which, in fact, acts as one coating, while the wires act as the other, of a Leyden jar. This condition of things weakens the current and prevents rapid signaling; but it is not often that underground wires are of sufficient length for the currents they convey to suffer seriously from this cause. It is far otherwise with the submarine cables, some of which (as those which cross the Atlantic) are 2,000 miles or more long. Special means have then to be taken to obviate the delay, and even failure, of transmission. The most effectual seems to be employing alternate positive and negative currents, as then each one as it passes through the cable counteracts the effect of its predecessor. The use of the exceedingly delicate recording instruments already referred to, is another important consideration, as a much weaker current is then able to suffice.

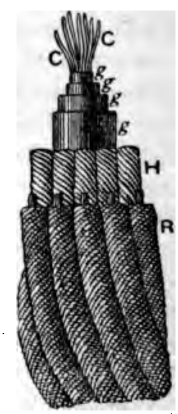

FIG. 39.—Section of an Atlantic cable. R, outer casing of tanned hemp ropes enclosing stout iron wires; H, inner casing of tanned hemp ropes surrounding the four gutta-percha layers *g g*; C C, strand of copper wire (untwisted) forming the conductor by means of which the messages are transmitted.

Submarine cables, especially when of great length, require to be exceedingly strong, in order to withstand the enormous pressure of water they encounter when being lowered, the buffeting of the waves near shore, and the friction against the uneven and often rocky bed of the ocean. The Atlantic cables, of which there are now nine, are made of seven strands of copper wire, covered with four layers of gutta-percha encased in tanned hemp. Over this

are twisted stout iron wires, also covered with hemp. Fig. 39 gives a representation of a portion of an Atlantic cable, showing the different layers.

One of the most important improvements in modern telegraphy is the introduction of the duplex system, which enables two messages to be sent in opposite directions along the same wire at the same time. In order to do this, it is necessary that when a signal is transmitted from one station to another, the receiving instrument at the sending station should not be affected, but remain free to indicate any message traveling to it from the opposite direction. This end is attained in various ways; and not only has duplex telegraphy come into constant use, but still further developments have taken place, so that a single wire is now able to convey four or more messages at the same time. Quadruplex telegraphy, however, entails the necessity for two sending and two receiving instruments at each station.

Currents of low electro-motive force are the most suitable in telegraphy, as they are then less liable to leak, and the mechanical work required of them is very slight. They are consequently almost exclusively generated by galvanic batteries. A form of Daniell's cell has been chiefly adopted in England, but the Leclanché is also excellent for telegraphic purposes and is coming widely into use.

This slight and inadequate sketch can give but a faint idea of the enormous proportions to which the science of telegraphy, for it is a science in itself, has now attained, but indeed no assertion of the fact is necessary, for we are brought face to face with it every day and almost every hour of our lives. Those multitudinous wires spreading over our continents and spanning our widest oceans may well strike us with a feeling somewhat akin to awe, for they are the nerves of the world, connecting its centres of intellectual, political and commercial activity with the remotest individual life, and flashing interchanges of thought between nation and nation.

CHAPTER V.

THE TELEPHONE.

Novelty of the idea of transmitting spoken words—Reis's telephone—Graham Bell's telephone—Weakening of the sound in transmission—Invention of the microphone—Its principle—Combination with the telephone—Transmitting and receiving instruments used in England—Feebleness of telephone currents—The Telephone Exchange system—Transmission of concerted music—Telephone wires—Necessity of guarding against induction—Means employed—Effect of earth currents and atmospheric electrical disturbances—Sensitiveness of telephone made useful as a test for weak currents—The microphone employed for medical purposes—The phonograph.

AS we have seen in the preceding chapter, the possibility of communicating at a distance by means of magnetic signs, though it had never been successfully attempted when the electric telegraph was invented, was no new idea. The transmission of spoken words, however, had not even been thought of, and its accomplishment came with almost as much surprise on scientific men as on the general public; but during the last twenty-five years we have become so used to talking with persons many miles away from us, that the thing has almost ceased to excite wonder, and in many of our large towns telephonic communication is becoming as important and common as that by telegraph.

The first telephone was invented by a German, Reis, in 1860. It could not, however, transmit articulate speech, but only musical notes, whose vibrations are so much less complicated than those of the human voice in speaking that they are far more easily reproduced.[1] One of the earliest forms of Reis's telephone consisted of a conical tube of wood, across the narrow opening of which was stretched an exceedingly fine membrane. One end of a narrow strip of platinum foil rested on the centre of this membrane, while the other was attached to a binding screw. A second strip of platinum attached to another binding screw, and having a small pointed projection for making contact, was so adjusted that one end just touched that portion of the first platinum strip which rested on the membrane. The binding screws were connected to a battery, and to a wire through which the sounds were to be transmitted. When a musical note was sounded close to the membrane, the latter was set in oscillation, and at each complete vibration (*i. e.*, movement *to and fro*) made and broke circuit once, by means of the motion imparted to the platinum

[1] The possibility of reproducing sounds at a distance depends on the fact that each one is caused by certain definite and periodic vibrations. If these can be transmitted in their entirety to another place, the sound must naturally be reproduced at that place.

strips. This interrupted current was transmitted through the line wire to the receiving instrument, which consisted of a violin, on whose bridge was fastened an upright knitting needle, enclosed in a coil of fine silk-covered copper wire. The alternate magnetization and demagnetization of the knitting needle as the current flowed or ceased in the coil, produced the sound which always occurs when iron is thus treated; but since the number of times the needle was magnetized and demagnetized exactly corresponded to the number of vibrations communicated by the musical note to the membrane whose motions started and interrupted the current, those vibrations were again exactly reproduced in the motion transmitted by the needle to the air, and the note was sounded once more. Reis afterwards made many improvements in his telephone, but he never succeeded in getting it to speak. In the first place, no instrument depending entirely on interrupted currents would be delicate enough for this purpose;[1] and in the second, though he constructed very elaborate mouthpieces for his transmitters, he paid but little attention to those of his receivers, though it seems obvious enough now that they were by far the most important, being directly concerned in the reproduction of the sounds.

The first speaking telephone was invented by Professor Graham Bell, a naturalized American citizen, about four years after the appearance of Reis's telephone. It consisted of two exactly similar instruments, one used as a transmitter and the other as a receiver, and its principle is easily understood by reference to Fig. 40. A steel magnet M is terminated at the end near the mouthpiece P by a piece of soft iron surrounded by a coil of very fine copper wire, covered with silk, and having its terminals permanently connected to the binding screws S S, one of which is connected to the line wire and the other to earth. Over the coil is a thin disc of soft iron, D, tightly fastened at the edges, but with its centre free and nearly touching the end of the magnet. Above the disc is the mouthpiece, P, spoken into in the case of the transmitter, and held to the ear in the case of the receiver. When the transmitter is used, the pressure of air against the thin iron diaphragm is altered with every inflection of the speaker's voice, and it is consequently set in vibration, making (to the eye) imperceptible movements backward

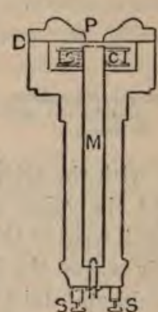

FIG. 40.—Section of Graham Bell's Telephone.

[1] The experiments of Graham Bell, whose telephone is described in the text, led him to distinguish between three kinds of currents: *intermittent* (when the current is periodically interrupted), *pulsating* (when its strength rises and falls suddenly), *undulating* (when its strength rises and falls gradually); and it is these last which are principally concerned in the transmission of human speech.

and forward in front of the wire coil, and thus starting alternate currents in it which are transmitted through the line wire to the coil of the receiving instrument, strengthening or weakening the magnetism of its core according to their direction. The result of this is to cause the second diaphragm to be attracted more or less strongly with every changing current, and so to vibrate in exactly the same manner as the diaphragm of the transmitter, imparting a similar motion to the air, and thus reproducing the sounds which originally started the currents. In fact, there is here a transformation of energy, precisely analogous to that which takes place between a dynamo and an electro-motor; only instead of mechanical motion being changed into electric currents by the dynamo and back again by the motor, we have sonorous vibrations transformed into electric currents in the telephonic transmitter, and restored to their original form in the receiver. The analogy can be pursued further. Just as the same amount of work is not given out by the electro-motor that was expended on the dynamo,

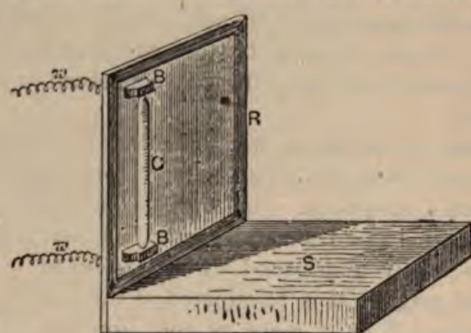

FIG. 41.—Microphone. C, carbon pencil; B B, carbon blocks with slight depressions (not represented), on which the ends of the pencil loosely rest; R, resonant board; S, wooden slab; *w w*, connection to battery.

so with the telephone also loss occurs in the process of transmission, and the voice given out by Graham Bell's original apparatus was much weaker than that which it had spoken in the first instance. For this reason the instrument was not altogether satisfactory, though it could and did transmit perfectly intelligible messages over a considerable distance.

What was wanted in order to enable the telephone to attain the great practical importance which it has now reached, was the discovery of some means by which the weakening of the sounds transmitted could be obviated. Hughes, whose printing telegraph was mentioned in the preceding chapter, accomplished this by his invention of the microphone, some form of which is now invariably used as transmitter in telephonic circuits. The action of the microphone depends on the principle, that if the pressure between conductors in contact is altered, there is an alteration in the electrical resistance of the circuit of which

they form a part; so that if the pressure is lessened the resistance is increased and the current becomes weaker, while increase of pressure entails diminution of resistance and the current becomes stronger. Carbon is the substance best adapted to contacts of varying resistance, and carbon is consequently used in nearly all microphones, of which FIG. 41 represents a simple but very effective kind.

When this instrument is placed in circuit with a telephone and used as a transmitter, the sounds emitted by the former are often very much louder than the original ones, simply because the varying pressure between the carbon pencil and its supports so affects the currents as greatly to strengthen the vibrations to which they give rise in the receiving diaphragm. In fact, not only are audible sounds made louder, but sounds quite inaudible to the unaided ear are rendered perfectly distinct; the walk of a fly even, over the sound-board of the microphone, being clearly distinguished in the telephonic receiver, and words spoken at some yards distance from the former being distinctly heard in the latter.

The instruments most used in England are the "Blake" transmitter, a form of microphone, and the "Bell" receiver, which is simply a Graham Bell telephone as described above. Beside a battery and the transmitting and receiving instruments, it is found advisable to include an induction coil in the circuit, the battery and primary coil being in connection with the transmitter, and the secondary coil with the receiver.[1]

Telephonic currents are calculated to be millions of times weaker than those used in ordinary telegraphy, and their alternations are so excessively rapid that there is no instrument delicate enough to make their presence known by optical signs. Their ready detection by the ear is consequently a striking proof of its extreme sensitiveness to any periodic movement, however slight.

The Telephone Exchange system, owing to which telephonic communication in our large towns has reached its present state of perfection, must not be passed over in silence. In principle it much resembles an electric-lighting installation. Just as the latter has its central and sub-stations, so the Telephone Exchange has its central and local exchanges connected by means of "trunk" wires. Each local exchange is connected to one or more others, and every subscriber has a private wire by means of which he can communicate with the local exchange to which he is attached. He is provided in his own house or office with a telephonic apparatus, consisting of a transmitter, a receiver, a battery, and a small magneto machine for making call signals, and a number by which he is to be known at the

[1] In the original Graham Bell telephone no battery was needed, the currents being generated in the transmitter by the movements of the diaphragm in front of the magnet; but where a microphone is used a separate generator is required.

exchange is assigned to him. When he wishes to speak with another subscriber, he signals to his own local exchange, and if the second subscriber belongs to it also they are put in immediate communication by having their respective telephonic circuits connected to each other. If the second subscriber belongs to a different local exchange, the signal is sent on to that, and communication is then opened between the persons who wish to converse by means of the two exchanges. If, however, the subscribers belong to local exchanges, which are not connected with each other, the Central Exchange, with which all are connected, is signaled, and communication is set up through that. The institutor of this exceedingly practical and well devised system was the father-in-law of Professor Graham Bell, Mr. Hubbard, who seems to have seen from the first the great possibilities of his son-in-law's invention.

The telephone is now often used for the transmission of music as well as of speech, whole concerts being made audible at distant places. Special arrangements are, of course, necessary in this case, as many considerations have to be attended to. It is necessary that the instrumental and vocal performances should preserve their due proportion of sound with regard to each other; that all extraneous sounds, such as persons walking about the stage of the concert-room, etc., should be excluded; and that the position of the singers should not interfere with the effect produced. All these difficulties have been successfully surmounted, even that of sufficiently insulating the transmitting microphones from any sounds but the music. To effect this they are placed on thick layers of lead covered with gutta-percha.[1]

It is most common to employ overhead wires for telephonic purposes, but in some places (as in Paris) underground cables are used. In any case, it is most important if the telephone wires are near others employed for different electrical work—such as telegraphy—to guard against the effects of induction, as the extreme sensitiveness of the telephone renders it specially liable to be interfered with by them,[2] and to have its true message interrupted or spoiled by sounds which have nothing whatever to do with it. A return wire (instead of the

[1] It is exceedingly difficult to insulate sound, and no substance so perfect for this purpose as gutta-percha is for insulating electricity has yet been discovered. Professor Hughes, the inventor of the microphone, says, "The question of insulation has now become one of necessity, as the microphone has opened to us a world of sounds, of the existence of which we were unaware. If we can insulate the instrument so as to direct its powers on any single object, as on a moving fly, it will be possible to investigate that object undisturbed by the pandemonium of sounds which at present the microphone reveals where we thought complete silence prevailed."—Quoted from "Electricity in the Service of Man," p. 723.

[2] It is, indeed, through using the telephone as a testing instrument that the fact before suspected has been proved, that any wire near another wire conveying an electric current has an induced current given rise to in it, however short the wires may be.

earth circuit) is generally found an efficient protection; but other means are also used for underground wires, one of which is to sheathe the telephone wire in an iron covering, so that induction shall take place in this and leave the wire itself unaffected.[1] "Earth currents" often produce disturbances in the telephone, causing a peculiar crackling noise, and thunderstorms give rise to very powerful effects. A flash of lightning too distant to be seen may produce a sound in the telephone, and it is stated that this often occurs before the flash, showing that inductive action must have taken place previous to the discharge.

The extreme sensitiveness of the telephone renders it very useful as a testing instrument for weak currents, there being apparently none so feeble that it will not give evidence of their presence; and a special apparatus devised by Professor Hughes, and called the *induction balance*, has been made of great use for the instantaneous testing of metals. It consists of a battery connected to two small primary coils, near each of which is a secondary coil in circuit with a telephone. The arrangements are so made that the currents in the secondary coils are opposite, and exactly equal in strength. Now, two equal and opposite currents destroy each other; so while this condition of things obtains, there is no sound in the telephone; but if one or the other current is ever so slightly increased or diminished in strength, the equilibrium of the balance is disturbed and an electro-motive force arises sufficient to cause a sound in the telephone. The testing of metals is thus carried out. Within each secondary coil is a box containing the specimens to be tested. If they are exactly similar, as for instance two genuine sovereigns would be, no sound is heard in the telephone; but if a difference exists, such as that between a true and false coin, the currents in the secondary coils no longer balance each other, and the telephone emits its warning note.

The microphone has been made very serviceable for medical purposes, and special instruments, such as the "miophone" and the "sphygmophone," have been constructed for the examination of the muscles, pulse, veins, arteries, etc., in the human body; and there is no doubt that in time the use of such apparatus will become widely extended.

During the last two years public attention has been much drawn to an invention as surprising and ingenious as that of the telephone, viz., the *phonograph;* and though this instrument is not electrical, it can hardly be passed over in silence, for it was devised and perfected by the great American inventor, to whom we owe so many marvels of applied electrical science; and, moreover, in its latest form the

[1] It is equally necessary to guard telephone wires from induction by each other, or else messages sent by one travel along the others also, and the words are reproduced at several receivers.

phonograph is driven by small electro-motors, deriving the necessary current from a battery of one or two cells. Electricity has therefore been utilized for it; and, moreover, it is stated that Edison is endeavoring to combine the phonograph with the telephone in such a way that even if no listener is at hand the latter can record its message to be heard when convenient. The work of the phonograph is to store spoken words or any desired sound, and to reproduce them when required. In order to effect this, it is necessary that the sonorous vibrations should make a permanent impression on some suitable substance, and that this impression should be able to give rise to exactly similar vibrations to those which produced it.

Edison's first phonograph consisted of a brass cylinder, turned by a handle, and on which was cut a spiral groove. A piece of tinfoil was wrapped round the cylinder, and over it was fastened a metal diaphragm, having a metal point attached which rested on the tinfoil. Above the diaphragm was a mouthpiece. When the latter was spoken into, the diaphragm was caused to vibrate, and the cylinder being set in revolution at the same time the metal point made a series of indentations, the depth of each varying with the strength of the vibration causing it; and this, of course, with the various inflections of the voice. These indentations were the record of the spoken words, and when the latter had to be reproduced a mouthpiece was held over a diaphragm exactly similar to the first, but placed with its attached point on the opposite side of the cylinder, which was revolved as nearly as possible at the same rate as when the record was being made. The second diaphragm was thus thrown into vibration exactly corresponding to that of the first, and the spoken words were reproduced. The sound was, however, thin and metallic; the record on the tinfoil wore out after being used a few times; and the instrument would only give satisfactory results in the hands of an expert, and not always then. Though interesting and ingenious, it was therefore only a scientific toy. In Edison's perfected phonograph, first exhibited in England in 1888, the brass cylinder of the original instrument is replaced by one of solid wax, and the metal point by a cutting style; so that, instead of a series of indentations, a wavy line is made in the spiral groove. The metallic twang and unevenness of speech is thus done away with, and the true timbre and all the inflections of the voice are reproduced; moreover, the record on wax is far more durable than that on the tinfoil, for one of these waxen cylinders may be used more than a thousand times, and yet show no sign of deterioration. Impressions can be taken of them to any number desired, so that without speaking the record more than once it can be indefinitely multiplied; and since the mechanism for revolving the cylinders, etc., is exactly the same in every instrument, they can be sent about by post to any person who possesses a phonograph, and be made to re-

produce their recorded speech or music for his benefit. Usually it is necessary to insert acoustic tubes in the ears in order to hear the phonograph, but the necessity for this can be obviated by placing a suitable funnel on the instrument, and its sounds are then made audible to a roomful of people at once. Distinctness is, however, lost by this process. The only obstacle which seems to lie in the way of the adoption of the phonograph for everyday purposes, is the fact that the cylinders require careful adjustment when put into the instrument, and therefore a certain amount of skill is necessary. It is hardly probable, however, that so slight a reason will long keep the use of the phonograph in abeyance. The graphophone, which, though improved from Edison's original phonograph, was not perfected by himself, requires less skill in the adjustment of the cylinders. On the other hand, its intonation is not so perfect.

CHAPTER VI.

ELECTRO-METALLURGY AND MISCELLANEOUS APPLIANCES OF ELECTRICITY.

Electro-plating—Dynamos used to generate the necessary currents—Quantity of current the important consideration—The "bath"—Anode must be made of the same metal which is to be deposited—Electrotyping—Method of obtaining fac-similes of medals—Of wood-engravings—Reduction of metals from their ores—Fusion of metals with high melting-points—Welding—Medical appliances of electricity—Sewer purification—Firing of submarine mines—Electric bells—Alarms—Clocks—Conjectured possibility of transmitting vision.

IT has already been stated that an electric current is able to separate metals from their solutions, and that the liberated metallic atoms are always deposited at the negative electrode, or kathode. This property of the electric current has been made of great practical use in the now familiar process of electro-plating, under which comprehensive term is usually included the covering of any metal with the coating of another, whether the latter be precious or not.

Formerly batteries were used to generate the required currents, but it is now found better and more convenient to employ continuous-current dynamos for this purpose. They are, however, of a different kind from those used for electric lighting and transmission of power, in both of which a current of high electro-motive force is required. This is not necessary in the case of the deposition of metals. Quantity of current is there the important consideration, and the dynamos are constructed accordingly. The method employed is as follows:

The object to be plated is made the negative electrode, and immersed in an electrolytic cell, known for this purpose as a "*bath*," and filled with an acid solution containing a salt of the metal, say silver, to be deposited. The positive electrode is made in this case of a plate of pure silver, and immersed in the same solution. The current is then passed through the bath, the electrolytic liquid is decomposed, oxygen is liberated at the anode, and silver deposited on the kathode, *i. e.*, on the object to be plated, and the process is continued until a coating of silver of sufficient thickness is obtained. If the plaiting is to be of gold or copper, exactly the same method is followed, only the solution is different, and in each case must contain a salt of the metal to be deposited. The object of making the anode of the same metal is, that by its gradually dissolving in the acid it may replace that which is being deposited on the kathode. Otherwise all the metal in the solution would be used up, and the process come to an end before the requisite thickness of coating had been obtained.

Electrotyping is another most important branch of electro-metallurgy. In this industry electrolytic deposition is used to obtain fac-similes of medals, wood-engravings, ordinary printing type, and even daguerreotypes. To obtain the fac-simile of a medal, a cast of the latter is first taken in some suitable substance, which if non-conducting is rubbed over with metallic powder to make it conduct. It is then immersed in a "bath" containing a solution of copper, and forms the negative electrode. The positive electrode consists of a solid bar or plate of copper. The current is then started and continued till a thick coating of copper is deposited on the mold, from which it can afterwards be easily detached. For fac-similes of wood engraving, a mold of gutta-percha is first taken from the block itself, and then subjected to electrolytic deposition of copper for twenty-four hours. The engraving is then found to be reproduced on a very thin plate of copper, which is strengthened by having melted type-metal run in at the back. From the "electrotype" many thousand impressions can be taken, and it is chiefly owing to the facility and accuracy of the process, combined with its comparative inexpensiveness, that the number of illustrated books has so greatly increased of late years. When all impressions had to be taken from the block itself but few good ones could be obtained, as the wood-engraving rapidly wore out.

The intense heat of the electric arc causes it to be extensively used in the reduction of metals from their ores. Even the most refractory yield to this treatment, but the current required in order to produce the necessary amount of heat, often attains several thousand ampères, the electro-motive force being, however, quite low. Currents of the same kind are also used for the fusion of metals with high melting-points, and for welding, complete success having been attained even

with aluminum, though all other means proved inadequate. For welding, however, it is not the electric arc which is used, but what may be called an "incandescent" method. The ends of the two pieces of metal to be welded are pressed together and the current passed through them, when the resistance it encounters at the point of contact causes the development of a heat sufficient to soften the metals, so as to allow of their being easily united.

The best known and most important practical appliances of electricity have now been touched on, but there are many minor uses (some of which should perhaps hardly be called minor) which deserve, at least, mention.

In the first place, attempts are increasingly made, and with increasing success, to use electric currents as curative agents,[1] and there can be little doubt that, as the natural electrical condition of the human body becomes better understood, they will prove of the utmost importance for medical purposes. Paralysis and kindred diseases are very frequently treated by electricity now ; but no such course should ever be pursued except by the advice and under the direction of a properly qualified medical practitioner who has made a study of the subject. Amateur attempts, when not positively dangerous, are far more likely to result in harm than good to the patient for whose benefit they are intended. Besides paralysis, certain kinds of tumor and aneurism have been cured by means of electricity. For this purpose electrolysis is employed ; it sets up chemical processes in the affected parts which result in the dispersion of the tumor or the hardening of the aneurism.

There is a hope that by means of a recent invention electrolysis may be utilized for a yet more important purpose than the cure of disease, viz., its prevention on a large scale, through ridding sewers of their poisonous gases, and thus rendering them innocuous. Electric currents have been also experimentally applied with some success to agriculture.

From these beneficial uses, it seems sad to turn to the destructive purposes which electricity is made to serve in warfare. It is now almost the sole agent employed for firing submarine mines and torpedoes, and many most ingenious contrivances have been devised, enabling an operator on shore to explode a mine some distance out at sea, at the very moment an enemy's vessel is passing over it.

Besides lighting, electricity is made to serve various domestic purposes. Electric bells are now so common and so evidently superior to all other kinds that they will soon have no rivals left. Electric alarms are also frequently used in large establishments, and in some cases electrically-controlled clocks. There seems, indeed, no end to the ways in which man may employ this marvelous and ubiquitous

[1] Induction currents are most frequently employed.

agent, so mighty in its resources and yet so easily controlled. It has even been hoped that by its means, vision, as well as speech, might be reproduced at a distance, and in fact some partially successful experiments in this direction were made more than ten years ago by Professors Ayrton and Perry. The problems to solve are so many and so intricate, however, and the constructive difficulties to be overcome so great, that it hardly seems possible an invention should ever be made which would be to the eye what the telephone is to the ear. Nevertheless, the marvelous adaptations of applied electrical science have astonished us so often that it may well be another surprise is in store for us here.

CONCLUDING CHAPTER.

"WHAT IS ELECTRICITY?"

Impossibility of giving a categorical answer to the question—Analogy with the case of gravity—Our knowledge of electricity in reality greater—Possible connection between the two sets of phenomena—Important results achieved by electrical science—Connection between electricity and light—Electro-magnetic disturbances propagated through space with the velocity of light—Space not empty—The ether—Meaning of radiation—Of "radiant" heat, light, and electricity—Electro-magnetic theory of light—Undulatory theory of light—Experimental proofs on which it rests—Necessity for similar proof in the case of electro-magnetic undulations—Hertz's experiments—Their conclusive result and consequent immense importance to physical science—Concluding remarks.

TO the question, "What is Electricity?" it is impossible as yet to give any certain answer—as impossible as to say what the force of gravity is; for, though the fact is perhaps not generally realized, we know as little of the nature of the one agent as the other. We say that "electricity," or electrified bodies, "attract;" we say that gravity is a force of attraction; but neither of these assertions is an explanation, it is simply a statement of facts. In reality more is known about electricity than about gravity, for it is ascertained to some extent in what way the electrical forces are propagated, whereas with respect to gravity we are absolutely ignorant as to its manner of working. We simply know that its observed effects are governed by unalterable laws, and it may perhaps be said that the only hope of discovering anything further respecting its action lies in the direction of there being found a connection between the phenomena of gravity and those of electricity, a possibility which gives a yet additional interest both to the experimental and theoretical study of the latter. Already a great part of the domain of physics, and nearly all

that of chemistry, has been revolutionized by the growth of electrical science, and if somewhat extravagant expectations are entertained about its future possibilities, they seem justified by the achievements it has already made.

In the present work but little has been formally said respecting any theory as to the nature of electricity, but it has been intimated that the electrical forces are propagated through the ether, and that there is a very close connection between electricity and light. To the observations already made it may be added that certain substances, notably selenium, have their electrical resistance very considerably altered if exposed to the action of light, also that a polarized ray of light in a strong magnetic field has its angle of polarization twisted into a different position.[1] But by far the most important point of connection between these two mysterious agents, light and electricity, is that the velocity with which an electro-magnetic disturbance is propagated through space is equal to the velocity of light, being in round numbers 186,000 miles a second.[2] Traveling at this rate, light takes eight minutes to reach the earth from the sun, and the fact of its thus requiring time to travel is sufficient to show us that space is not, as it is so often supposed to be, empty, but that there is something present in it which transmits light, and, we may add, transmits also heat and electricity. The structure of this something, which it has been agreed to call "ether," is now, and perhaps always will be, unknown, but it is understood that it must be totally different to that of any other form of matter with which we are acquainted, though it appears to possess what may be called the counterparts of ordinary material qualities, such as elasticity and density. Heat, light, and electrical energy are propagated through this medium in a way known as *radiation*, *i. e.*, in spherical waves. The term "radiant heat" is becoming familiar even to the non-scientific, but it must not be supposed that it designates any particular kind of heat. It simply means heat traveling in a particular kind of way, during which it does not appear as heat at all, but as motion; and the same is true of light and of "radiant" electricity. There is no light, as we understand light, except where the presence of gross matter modifies the action of the ether; the interplanetary and interstellar spaces are dark. Neither is there any sensible manifestation of heat or of electrical energy. But there is motion; and this motion is capable, under the right circumstances, of appearing either as light or heat or electrical energy.

If, however, light and electrical undulations are propagated through

[1] See note at the conclusion of the chapter, p. 147.

[2] By an electro-magnetic disturbance is meant such a disturbance as is given rise to, for instance, by the discharge of a Leyden jar, or the make and break of a galvanic circuit.

the same medium, with the same velocity, in the same manner, it is not difficult to conceive that they must be more than merely related; they must be to a great extent identical. This has been recognized by advanced scientific thinkers since the time—now more than twenty-five years ago—when the great English physicist and mathematician, Clerk Maxwell, published his "Electro-Magnetic Theory of Light," of which the first experimental proof was given in 1877 by Professors Ayrton and Perry, who found that the ratio of the electro-magnetic to the electro-static unit of electric quantity[1] was equal to the velocity of light, as Clerk Maxwell had shown that it must be, if light were propagated as an electro-magnetic disturbance. In 1888 another great step was made, for the existence of electro-magnetic waves, in all respects similar to those of light, was detected by direct experiment, and that date consequently marks a memorable era in the history of modern science. In order that the reader may be enabled to comprehend the nature of these now celebrated experiments, first carried out by a young German physicist named Hertz, and since him by others, reference must be made to what is known as the "undulatory theory" of light, and to the proofs on which it rests.

For a very considerable time it has been understood that light is caused by motion of some kind. The question was whether that motion was one of material particles shot out from the luminous body, as Newton supposed, or whether it was a vibratory movement started by the luminous body in the ether, through which it was propagated. The latter theory was always found by far the most capable of explaining luminous phenomena, and experimental proof of it was finally given by two eminent scientific men, Young and Fresnel, the one English and the other French, independently. Connected with any wave movement, there is a phenomenon called interference, which is caused by the action of waves on each other, and which can be roughly observed by any one watching water-waves turned back from a sea-wall upon those still advancing. It will be noticed that the direct and reflected waves meet each other in one of two ways, either crest joins crest and furrow furrow, with the result of making a much larger wave, or crest joins furrow and furrow crest, and there is a patch of comparatively calm water. A much better way of observing the effects of interference is to suspend a cord to the ceiling of a room, and taking the free end in the hand impart to it a series of periodical impulses. Waves are thus given rise to in the cord which run up to the ceiling, are there reflected, and return to the hand of the operator; and while this is going on, if the rate of motion of the hand be right for the length and mass of the cord, the latter will divide itself into a regular succession of loops, the centre of each one of which is a point of greatest amplitude of vibration, *i. e.*, where the swing of the cord

[1] Generally known as "v."

particles from side to side is widest, while between each loop is a point of no vibration, technically called a node. Where the loops occur, the direct and reflected waves meet each other in what is called the same phase of vibration (supposing they were water-waves, both would be rising and both falling at the same time); where the nodes occur, they meet in opposite phases of vibration (in water-waves one would be rising and one falling), so that the same point being acted on by two equal and contrary forces remains at rest.

Now, if light travels in waves, wherever direct and reflected waves of light meet each other there must be a similar phenomenon to that exhibited in the cord, and it can be observed by causing two pencils of red, or of any monochromous light to pass through two small apertures into a darkened room, and fall upon a white screen in such a way that certain portions of it are illuminated by reflected rays from both pencils, care being taken, as regards each pencil, that only light of one phase should reach the illuminated parts of the screen. There then appear on the latter alternate bands of the colored light and of darkness, which correspond exactly to the loops and nodes in the cord, the colored bands being caused by those light waves which meet in the same phase of vibration, and the dark by those which meet in opposite phases. That this is really the case can be proved by shutting off the light from one of the pencils, when the dark bands disappear, thus showing that they were caused by interference. This experiment places beyond a doubt the truth of the undulatory theory of light; and in order to prove the electro-magnetic theory of light, or, in other words, the existence of electro-magnetic undulations identical with those of light, an experiment of the same kind, but of an electrical nature, was necessary.

The difficulty lay in the extraordinary rapidity of vibration which it was necessary to attain, in order to procure waves manageable within the walls of a laboratory. The ordinary oscillations of a Leyden jar discharge, which are at the rate of one million a second, were far too slow, for the ether wave length corresponding to this period (viz., the millionth of a second) is 300 metres, and one of a few feet only was required. To obtain this it was necessary to produce vibrations of the order of 100 million per second, and even when this difficulty had been surmounted, by the construction of a special apparatus whose capacity, resistance and self-induction were so proportioned as to give vibrations of the required rapidity, there remained the question, How could they be observed? They could not be seen. Ether-waves which can be seen are waves of light, and their rate of vibration is several billion times a second. They could not be heard. To render them audible they must be made very much slower, as was done by Dr. Oliver Lodge in the experiment described in Chapter IV. of Part III. In order to observe electrical

waves too long to be seen, and too short to be heard, Hertz made use of the principle of resonance, the most familiar example of which is that of a tuning-fork, which when sounded is able to make any neighboring tuning-fork of the same pitch as itself sound also, simply because their periods of vibration being the same, the second tuning-fork absorbs the vibrations of the first, and gives out exactly similar ones. Hertz, therefore, constructed two electrical circuits whose periods of vibration were identical. One he called the oscillator, and the other the resonator. The latter included a small spark gap, and was placed between the oscillator and the wall. When vibrations were set up in the oscillator, induced vibrations were set up in the resonator, and in a darkened room an infinitesimal spark was seen to cross the gap. By moving the resonator about to different parts of the room, Hertz found that in some places the sparking was more active, and in some it ceased altogether, and he also found that these spots of electric activity and repose succeeded each other at regular intervals, thus showing that they were due to the interference of direct and reflected waves, and were, in fact, a phenomenon exactly similar to the nodes and loops in the cord, and the dark and light bands, described above. By further developments of his experiment, Hertz was able to prove that these electro-magnetic waves are transverse, like light waves, viz., that the vibrations take place across the line of propagation; and, moreover, that every effect which can be observed with the one kind of waves can be observed with the other. Thus, both alike can be reflected, refracted, and polarized. Nothing is, therefore, wanting for the complete establishment of the "electro-magnetic theory of light." Electrical, like luminous phenomena, are all referable to the action of the ether, and we may say either that electrical science includes the whole of optics, or that optics includes the whole of electrical science, whichever way we like to put it. This is the commencement of a very splendid generalization. It is, without doubt, one of the most important advances in physical science which has ever been made, and it is with a feeling of intense expectation that the question arises in our minds, "What will be the next?" Scientific men seem trembling on the verge of some discovery which will come nearer to the solution of the problems surrounding the ultimate nature of matter than even a few years ago was deemed possible. Will this discovery be made in our own generation, or in the next, or perhaps not for many more to come? We cannot tell. At any moment it seems possible, and yet it may be long deferred; but present knowledge would lead us to suppose that when it does come it will be as amazing in its simplicity as in the depth and wideness of its scope. Already some of our leading physicists are beginning to formulate the query—infinitely more far-reaching than that which heads this chapter—whether all existing things are not modifi-

cations of that ether but a short time since deemed hypothetical, and which is now proved to be the medium through which we receive the life-giving and life-sustaining energy emanating from the sun. Startling as such an idea may be at first sight, there is an inexpressible grandeur in the conception which it leads us to form of the unity of design pervading the whole of creation, and of that Infinite Mind which human reason—its faint reflection—is being more and more taught to realize as underlying and interpenetrating the "material universe."

NOTE ON THE POLARIZATION AND MAGNETIZATION OF LIGHT.

IT was mentioned in the preceding chapter that the vibrations of light are of the transversal kind, *i. e.*, that they take place across the line of propagation, and in a ray of ordinary light they are executed *in all directions* across this line. If, however, such a ray be caused to pass through a thin slice of tourmaline, or a Nicol's prism, it emerges with all its vibrations reduced to one plane, and is in the condition known as that of *plane polarized light*, the tourmaline, or Nicol's prism, through which it has passed being called the *polarizer*. The plane of polarization can be discovered by placing a second slice of tourmaline, or Nicol's prism, called the *analyzer*, in the path of the polarized ray, for a position can be found for the analyzer in which it is opaque to the incident polarized ray, whose light is consequently quenched altogether. This position is always at right angles to that of the polarizer, to the plane of polarization of the ray, and to the position in which the analyzer would itself polarize light.

By the "magnetization" of light, discovered and named by Faraday, the following effect is meant. If a bar of a certain kind of "heavy glass"[1] be placed across the poles of a powerful electro-magnet, and a ray of polarized light caused to pass through it and enter an analyzer on the opposite side, it is found that when the current is passing through the coils of the electro-magnet the position in which the analyzer causes darkness to occur is not the same as when there is no current. This shows that the plane of polarization of the ray has been twisted round under the magnetic influence, and proves a direct

[1] A tube containing bi-sulphide of carbon will have the same effect, which can also be produced in a minor degree by other substances, and to a very small extent by air.

action of magnetism on light. The direction in which the plane of polarization is twisted is for most dia-magnetic substances the same as that of the magnetizing current, but for many magnetic substances contrary to it. Further proof of the rotatory effect produced by magnetism on light is given by the fact that a polarized ray reflected from a magnet or an electro-magnet also has its plane of polarization twisted round. If the reflection takes place from a pole, the plane of polarization is turned in a contrary direction to that of the flow of the magnetizing current; if from a point at the side of the magnet, in the same direction, provided the planes of incidence and polarization are parallel. If they are perpendicular to each other, the direction of rotation is only the same as that of the magnetizing current if the angle of incidence exceeds 75°. For lesser angles the rotation is opposite to the direction of the current.

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